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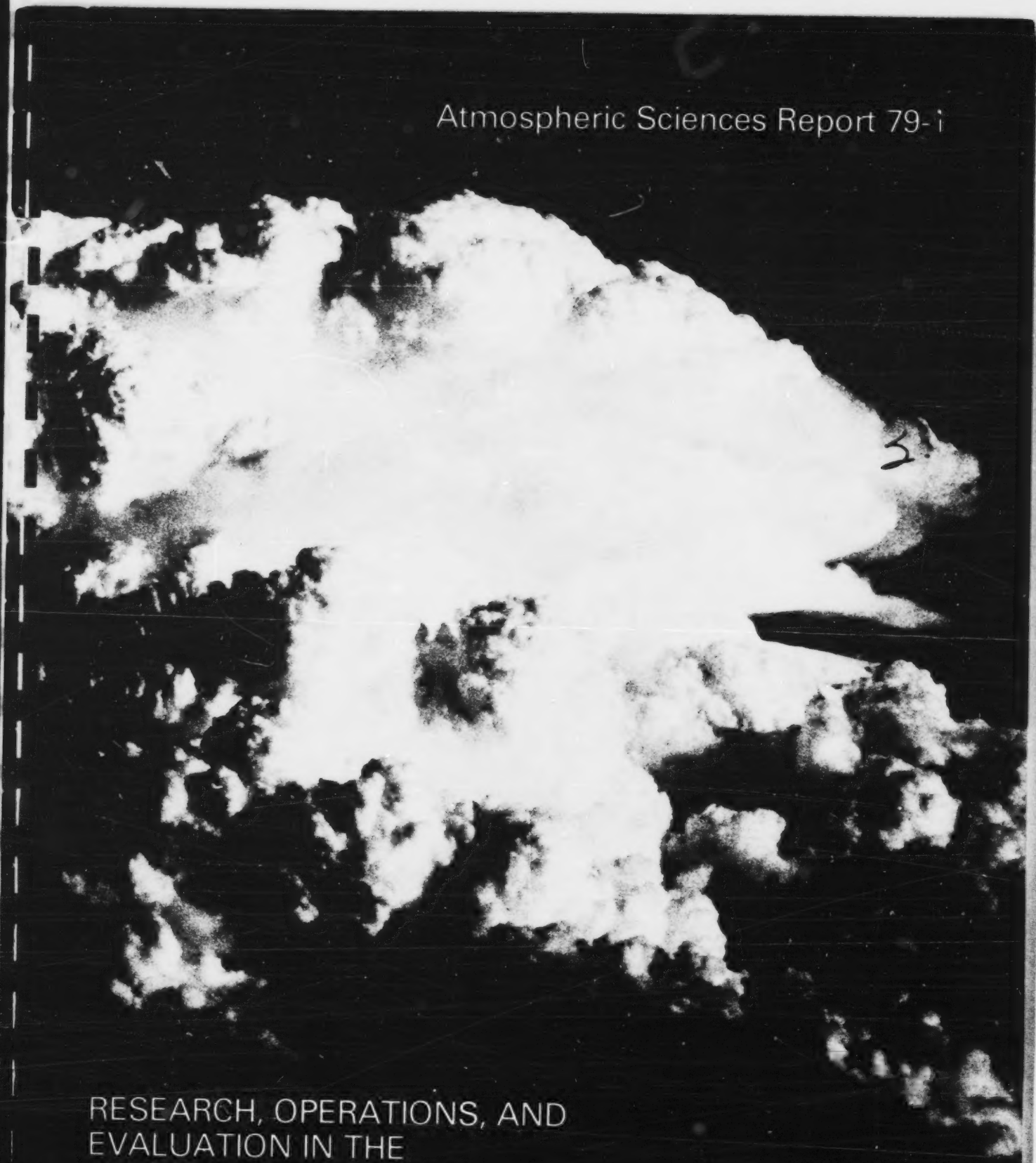

RESEARCH, OPERATIONS, AND EVALUATION IN THE ALBERTA HAIL PROJECT

Volume 3: Operations

RESEARCH COUNCIL

RESEARCH, OPERATIONS, AND EVALUATION IN THE ALBERTA HAIL PROJECT 1974 - 1978

Volume 3
The Operations

by

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RADAR ENGINEERING, OPERATIONS, AND APPLICATIONS

S. Leung

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RADAR ENGINEERING, OPERATIONS AND APPLICATIONS

S.K. Leung

THE ALBERTA HAIL PROJECT RADAR SYSTEMS

Since their invention during World War II, radars have been adopted for use in meteorological research. In Alberta a high resolution polarization-diversity radar, interfaced to a digital computer, is operated routinely in a hail research and suppression experiment. The development and operation of this specialized radar and other Alberta Hail Project (AHP) radar systems is discussed in this report.

DEVELOPMENT OF THE RADAR SYSTEMS

Radars (Radio Detection and Ranging) were first used in World War II to detect hostile aircraft. Radars detect the presence of remote objects, and measure the distance to these objects. During the war their applicability to weather observations was quickly recognized. Weather radars are now built with beam widths of one to two degrees and pulse durations of 1 to 5 μs, making it possible to resolve precipitation patterns in detail. When a pencil beam antenna is rotated about its vertical axis and elevated in small increments from the horizon, a three dimensional picture of the precipitation can be obtained using radar scopes called Plan Position Indicators (slant range PPI's). The three dimensional scan cycle takes only a few minutes, ensuring excellent time resolution in tracking the development of weather patterns (Marshall and Ballantyne, 1973).

The S-Band Radar

Here in Alberta, radars are an important tool in the study of the nature of hailstorms and the mechanisms of precipitation growth. Hail research was first sponsored by the Alberta Research Council (ARC), National Research Council (NRC), McGill University, and Canadian Meteorological Service beginning in 1955. In 1956 a radar was purchased to provide quantitative data on hailstorms. An X-band radar with camera-equipped PPI's was installed in 1957 and provided data on storm tracks and intensity until 1965.

Because of the high attenuation of the X-band signal through precipitation, a lower frequency was utilized. An S-band radar with a broad vertical antenna beam was brought into operation in 1963. It later became necessary to alter the antenna to provide a higher resolution pencil beam. By 1967 a 22-foot parabolic dish with pedestal had been purchased, tested, and finally installed (Fig. 1). The principal characteristics of this radar are:

frequency:	2.880 GHz
pulse repetition frequency:	478 Hz
pulse duration:	1.7 μs
typical peak power:	200 kW
polarization:	arbitrarily selectable
beam width:	1.15°
antenna gain:	43.2 dB
antenna rotation rate:	8 RPM
elevation program:	spiral scan: 1° revolution to 8° or 20°.

This sophisticated radar can transmit radiation of any polarization. It is equipped with dual receivers, and can measure the main (port 2) and orthogonal (port 1) components of the backscattered radiation and thereby determine depolarization effects (alteration of the transmitted polarization into a different polarization) of hydrometeors. Hail and rain sometimes produce different depolarization effects, so it is often possible to distinguish the two in storms. It is also possible to measure the phase difference between the two components in two additional channels (see section on phase detection). The S-band radar is therefore capable of simultaneously supplying four channels of radar data. This radar is operated routinely in a surveillance scan mode, and the development of many hailstorms in central Alberta has been recorded (Renick, 1971; Chisholm and Renick, 1972; Barge, 1972, 1974; Humphries, 1974; Goyer, 1975). A block diagram of the present radar system is shown in figure 2.

Radar Data Recording

Quantitative data from weather radars are difficult to obtain. To be able to do this the receivers must be calibrated daily in order to relate output video voltages to received echo power levels. Careful monitoring of the transmitter power and frequency is also required. To maintain a permanent record of the data, PPI (Plan Position Indicator) cameras are used. For each revolution of the antenna, data from the main and orthogonal components are recorded on film using gray shades. The gray shades allow different power levels of the reflectivity and CDR to be distinguished (Barge, 1974). Film data are extremely difficult to analyze because of the poor spatial and intensity resolution. However, recent advances in computer and digital technology have provided solutions to this problem. Now, a computer interfaced to a radar is able to record the received power levels with an unprecedented intensity resolution of less than 1 dB. The data, which are stored on magnetic tapes, are easily retrieved for post-facto analysis. Computer-generated graphics greatly enhance the researchers' ability to analyze this storm data. With the introduction of weather modification experiments, there is now considerable demand for computer-generated, high resolution, real-time radar displays.

The radar data collected by the AHP were exclusively on film or chart records until 1974 (Fig. 3). Some improvements were made in the quality by selecting better film and Cathode Ray Tubes (CRT) for the

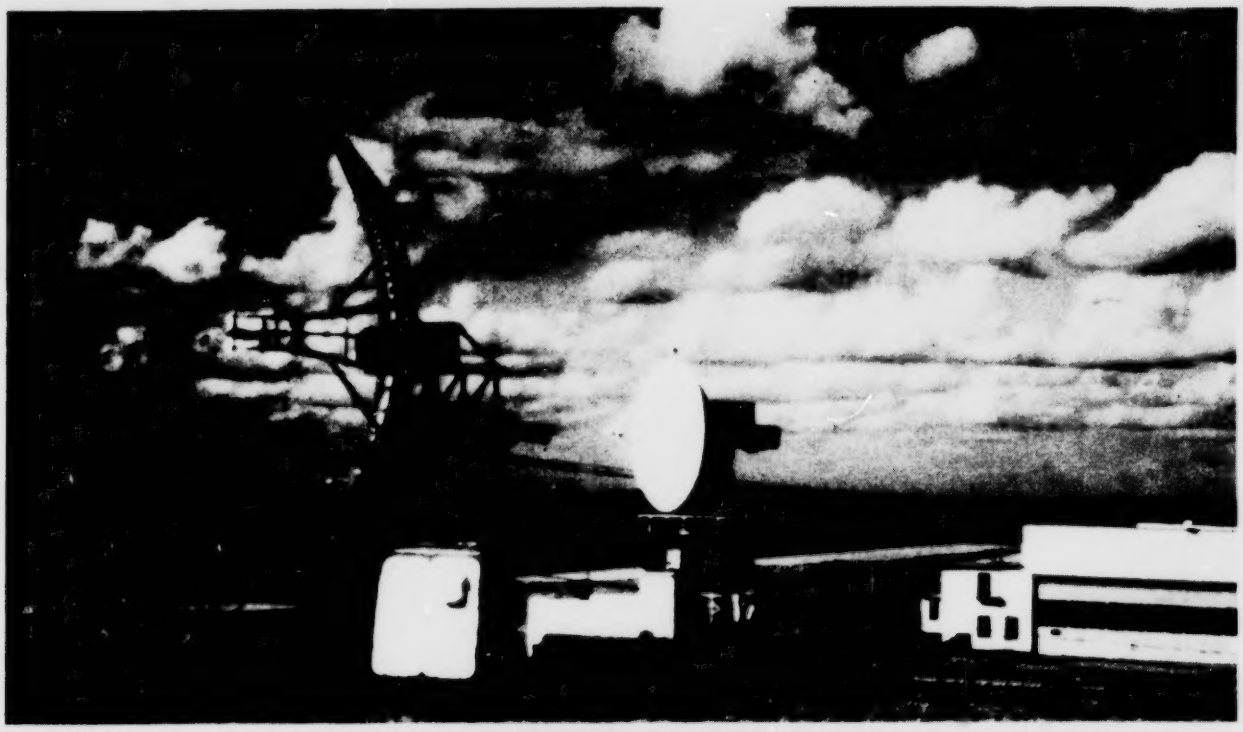


FIGURE 1.(a) The Alberta Hail Project radars, 1968 and 1978

camera-equipped PPI's, but the data on film were still less than perfect due to unstable electronics in the PPI's. In 1974 the first C-band radar data were recorded on computer magnetic tapes, but with interpolated azimuth and range information. By 1975 the first S-band dual channel data with digitized azimuth and elevation angles were recorded. Daily radar receiver calibrations were also recorded in the computer, and the use of new PPI's improved the film data used as a backup to the data logged in the computer. In 1976, a graphics program (Ramsden *et al.*, 1976) was developed to facilitate post-facto analysis of radar data. Capacity to record four channels of data was also added, together with a memory buffer to ease computer timing problems. In 1977, installation of azimuth integrator circuits allowed more computer time for production of real-time displays and rainfall maps. The real-time display is able to display both contours of storm intensity levels in detail, and aircraft tracks, allowing greatly improved control of seeding operations (Humphries *et al.*, 1978). Beginning in 1977, C-band and four channels of S-band data were collected simultaneously. Because of the research demand on the original computer, a second smaller computer was purchased for the 1978 hail season to record data and produce real-time displays.

The X-Band Radar

When cloud seeding experiments were started, an accurate aircraft-tracking system was needed. Seeding controllers required exact aircraft positions on PPI's to direct aircraft to potential seeding targets. In 1970 seeding aircrafts were equipped with S-band transponders. The transponders responded to signals emitted by the weather radar. Because of the narrow (1.15°) pencil beam of the S-band antenna only one transponder reply every 1.5 min. was possible. The resultant information on aircraft position was unsatisfactory. Given the high resolution required, an X-band tracking radar with a broad vertical antenna beam was added in 1971 to detect transponder-equipped AHP aircraft. This pill-box antenna allowed aircraft to be detected every 7 sec, but it had to be

FIGURE 1.(b) The Alberta Hail Project radars

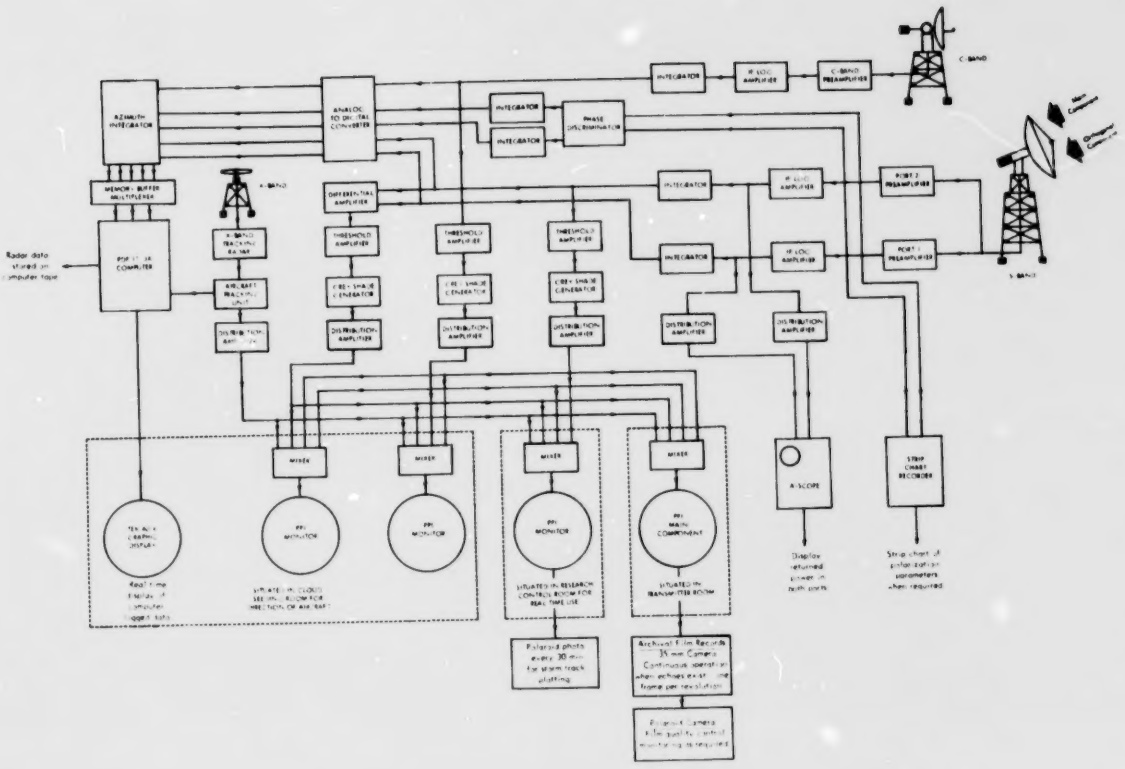


FIGURE 2. Simplified block diagram of the radar receivers

synchronized to the S-band antenna such that aircraft information could be directly displayed on the PPI's. Due to the errors in analog slaving, a digital synchronizing system (Aircraft Tracking Unit ATU) was designed and first installed in 1975 (see section on aircraft tracking). With this system the antennas rotated independently while the aircraft information was displayed on PPI's in proper registration with the weather radar echoes. Much effort was made to provide reliable aircraft positions to the PPI's and the computer. A new transmitter was installed in 1974 and the receiver sensitivity was improved by adding an RF (radio frequency) amplifier, a wider-band (4 MHz) logarithmic amplifier, and better threshold circuits. Transponders were checked daily for power and frequency instabilities, and new frequencies were obtained to reduce interference from commercial aircraft weather radars. A sensitivity time control, which makes the radar sensitivity a function of range, was also added to minimize ring-around problems (ring-arounds are caused by secondary antenna beams, called side lobes, interrogating the transponders). Characteristics of the X-band tracking radar are:

frequency transmitted:	9.475 GHz
frequency received:	9.410 GHz
pulse repetition frequency:	478 Hz
pulse duration:	2.0 μs
typical peak power:	150 kW
polarization:	vertical
beam width horizontal:	1°
vertical:	16.5°
antenna rotation rate:	10 RPM.

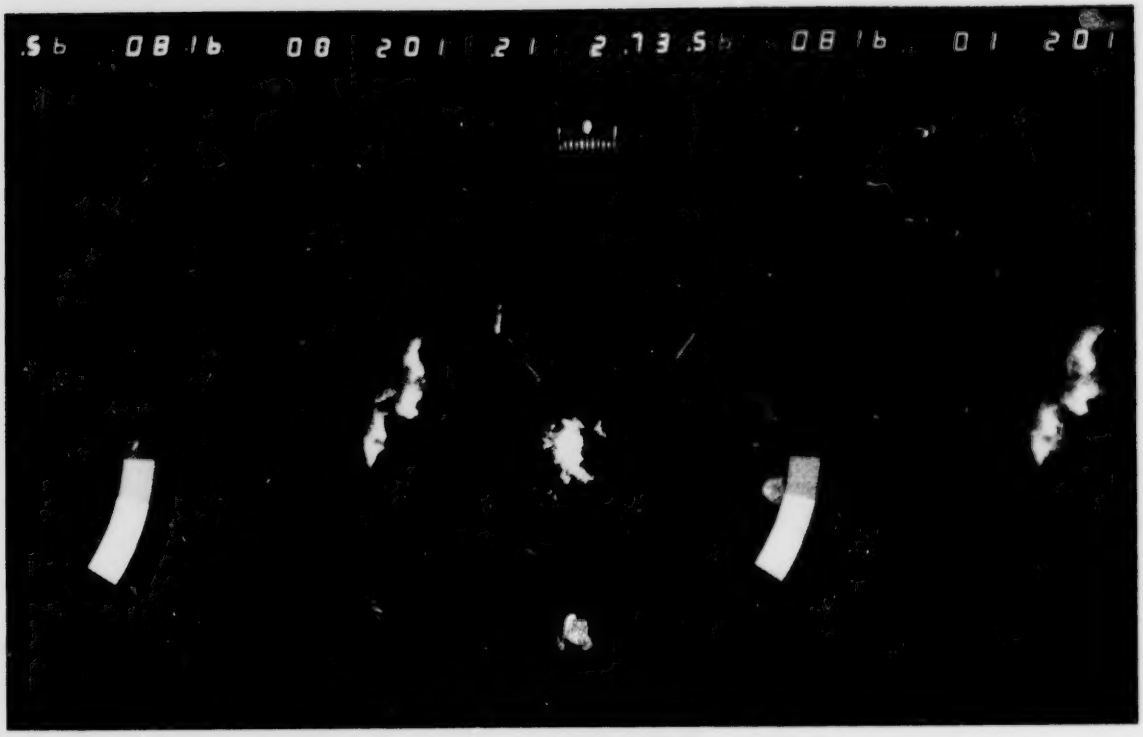
The C-Band Radar

In 1973 an old standby X-band weather radar was installed for use when the S-band was not usable because of high winds. This X-band radar was soon used as a source of spare parts for the X-band tracking radar then in use. Subsequently a new C-band weather radar, as well as a new X-band transmitter, was purchased for the 1974 hail season. The purchase of the C-band radar proved prudent as the S-band radar was not available throughout 1974. The C-band radar also provided the opportunity for dual wavelength radar observations and research, which can reveal additional information about hydrometeor types in a storm (Barge and Humphries, Volume II). The main characteristics of this C-band radar are:

frequency:	5.635 GHz
pulse repetition frequency:	478 Hz
pulse duration:	2.0 μs
typical peak power:	200 kW
polarization:	horizontal
beam width:	1.5°
antenna gain:	40 dB
antenna rotation rate:	5 RPM
elevation program:	step scan: 1.5° per revolution to 9° or 21°.

Other Equipment

Over the years many pieces of equipment have been added to the AHP radar facility; these additions have



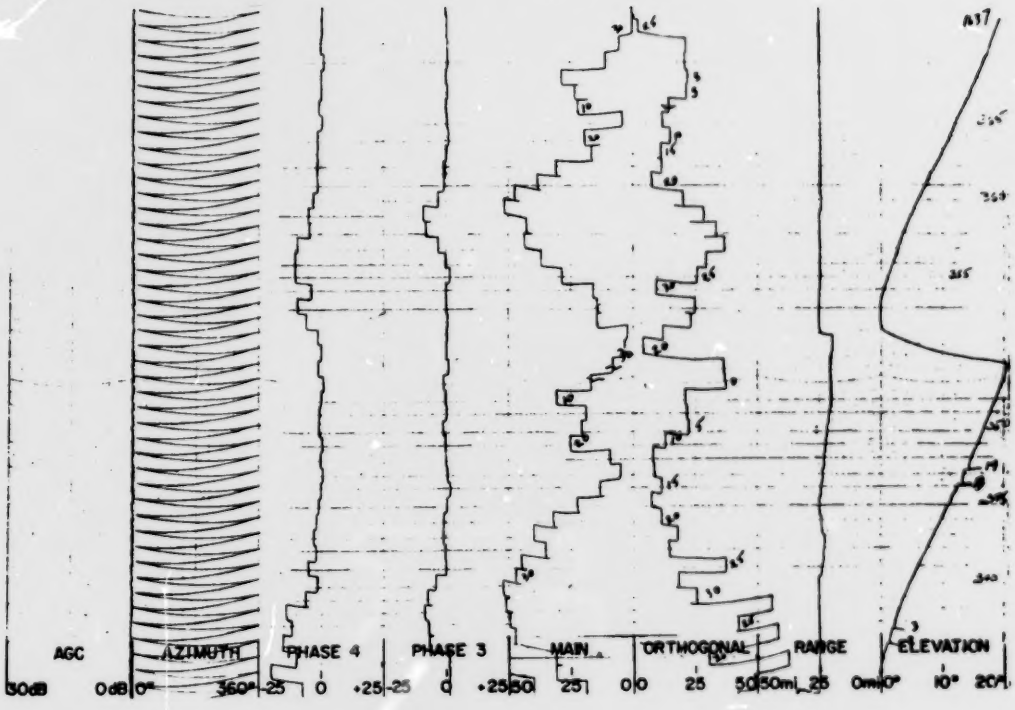


FIGURE 3. Examples of film and chart records

made research tasks and seeding operations much simpler. The more noteworthy additions were:

(1) Radio systems to communicate with aircraft and ground vehicles; these are used to direct seeding aircraft to targets and ground vehicles to precipitation sampling areas.

(2) Phase detection equipment to calculate preferred orientation of particles in a storm (see section on Phase detection circuitry); hailstones tend to fall more randomly than raindrops, so this equipment provides information on the type of particles in storms (Hendry, *et al.*, 1976).

(3) Range integrators to average received radar echoes over 1 km rank intervals (see section on range integrators).

A Historical Review

A chronicle of major events since 1967 is listed below:

April 1967	S-band radar pedestal arrived in Penhold from NRC
June 1967	single channel operations began
September 1967	dual channel data were available
April 1968	slow-speed drive installed in S-band pedestal
	monitor installed for antenna checks
	range gate installed for receiver
	FM radio system installed
June 1968	differential amplifer installed for CDR (Barge, 1974) measurements
September 1968	azimuth gate installed for receiver
	cloud seeding experiments started
April 1969	threshold, gray shade, and range ring circuits converted to solid state
	new IF (intermediate frequency) slip rings installed
	new solid-state, matched logarithmic IF (intermediate freezing) amplifiers installed in main and orthogonal component signal channels
	chart recorder installed
	FM repeater station installed at Sylvan Lake
September 1969	S-band gear box serviced
June 1970	S-band transponders in use with cloud seeding operations
	new VHF, AM ground-to-air radio installed
May 1971	8 and 20 degree elevation scan mode added to S-band
	X-band aircraft tracking radar installed
	X-band antenna synchronized to S-band antenna
May 1972	emergency power generator installed
	range ring, trigger, and video distribution amplifier chassis rebuilt
September 1972	X-band standby radar installed
April 1973	the first real-time digital clock installed
	computer ordered
September 1973	X-band standby radar used for parts for the tracking radar
	new tracking radar and standby radar ordered
	Processing graphics - terminal delivered
	S-band dismantled for bearing service
April 1974	C-band radar installed
	X-band transmitter installed
	computer installed
	peak detectors replaced by range integrators
July 1974	first C-band data recorded by computer, heading marker pulses used for azimuth reference
September 1974	S-band radar servicing completed
	new tower for the S-band test monitor installed
May 1975	new PPI's delivered
	aircraft tracking unit (ATU) installed
	new mixer boxes for the PPI's built
	new VHF radio installed
	radio control boxes built
	range integrator built for the C-band radar
June 1975	dual channel data recorded by computer
January 1976	aircraft tracking unit rebuilt
	radio tests solve noise problems
April 1976	integrator and threshold circuits rebuilt
	new IF slip rings installed in the S-band
	AC reference voltage for synchros (a device for the electrical transmission of angular position) and AC power supply for camera-equipped PPI's stabilized
	memory buffers and four-channel capability added to radar/computer interfacing circuitry
	new, wide-band, logarithmic amplifier installed in X-band receiver
	rebuilt analog to digital converters (ADC) and buffers in computer to radar interfacing circuitry
July 1976	new frequencies allocated to X-band tracking system
August 1976	phase measurement circuits completed
	tunnel diode amplifier (TDA) installed in X-band receiver
	new C-band antenna installed

January 1977	digital azimuth integrator circuits designed and installed into radar to computer interface circuitry
April 1977	new azimuth rotary joint installed in S-band pedestal
	gray shade, differential amplifier, elevation display, camera data display and X-band threshold circuits rebuilt
	electrical grounds improved
	C-band radar elevation to computer interfacing circuits installed
	limiter installed to protect TDA in X-band
June 1977	data from all four channels of S-band receiver recorded
	real-time display available for seeding operations
	rainfall rate maps produced routinely
July 1977	new S-band transmitter delivered
	dual wavelength measurements made
April 1978	new X-band antenna controller installed
	C-band AFC (automatic frequency control) circuit improved
	digital circuit added to X-band receiver to further reduce noise
	new elevation rotary joint installed in S-band
	second computer installed, for data recording and controlling seeding operations
August 1978	sensitivity time control (STC) added to X-band receiver

RADAR OPERATIONS

Operations Routine

Prior to 1973 the radar operations were the joint responsibility of the Alberta Research Council, the National Research Council, and McGill University. Engineers and technicians would arrive from Ottawa in the spring to prepare the radar systems for the hail season. When the installations were completed, the radar system would be turned over to the ARC or NRC technicians and McGill graduate students who operated the systems. The operations routine involved daily, early morning calibration of the radar receivers, which also amounted to a maintenance checkout. The radar was then ready for data collection and special experiments. However, on many occasions storms persisted into the night and the receivers were not calibrated because of early morning storm activity. In 1973, when NRC ceased to actively participate in the project and took on the role of consultant, more ARC personnel were hired to take care of the spring start-up operations. In 1974 the Alberta Weather Modification Board (AWMB) was established, and ARC continued to provide staff to operate the radars and carry out research.

As the radar and auxilliary systems grew in complexity, it became increasingly difficult to finish the routine maintenance checkouts and calibrations and be ready for early operations. For this reason, a 24-hour shift schedule was established in 1975. Since then, all calibration and checkouts were performed by the midnight-shift assistants who reported any necessary repairs to the technologists on the day shift. This allowed more time to clear up any difficulties and to prepare the radars for early operations. This 24-hour shift schedule has successfully reduced difficulties in operating the system.

During the early years, the hours of daily radar operation were determined by the forecast meteorologist who would predict when and where storms would develop. The radar was then turned on at the appropriate time and data recorded. Due to the uncertainty of weather predictions, some storms were discovered to be well developed by the time the radar was on. To remedy the situation, the standby radar was used to monitor early storm developments. However, questions still remained as to when to start the S-band and begin data-recording. In 1977 the nominal operating hours for the S-band radar were established to be from 1200 to 2100 hours, to be expanded according to weather conditions. This ensured smooth operations, and many first-echo data were obtained which previously would have been unrecorded. There was also an increasing interest in rainfall amounts and late night storm activities in central Alberta. Consequently in 1978, 24-hour collection of radar data was started (data from the standby radar was recorded when the S-band radar was not operating).

Personnel

Two ARC radar meteorologists provided leadership in the radar section and were responsible for the weather radar research into precipitation growth in storms. The number of ARC personnel involved with the radar system's engineering has changed through the years. In 1972 there were only two technologists. By 1975, an engineer and two full-time and one part-time technologists were needed to maintain the radars. Since 1977, the radar systems have become more reliable and only two technologists and an engineer were required. During the hail season six summer assistants were hired and were given one month of intensive training (Leung, 1977). The assistants rotated in a shift schedule of six days on and three days off, covering 24 hours a day. One assistant was required for the day shift and one for the evening shift, but for safe operations two assistants worked the midnight shift. The technologists also worked shifts to cover the seven day week. The engineer worked regular days but was on call in case of emergencies. This shift structure has been used successfully for four years.

Operational Computer Programs

During the past few years, various computer programs have been developed to assist in radar operations. The more important ones are:

(1) LOG - Events concerning the operation of the radar systems are recorded by this program onto disk files.

(2) TAP - Records of the magnetic data-storage tapes such as data period, date, and tape number are kept by this program.
(3) ACLOG - Aircraft positions as supplied by the ATU are recorded onto disk files.
(4) ANTPOS - Antenna positions are printed at the computer terminal.
(5) ACPOS - Aircraft positions are printed at the computer terminal.
(6) BITCHK - A test program which checks that antenna position data going to the computer are valid.
(7) CALIBS - The S-band receivers are calibrated using this program. The recorded data values can then be correlated to absolute power levels and phase angles.
(8) CALIBC - The C-band receiver is calibrated using this program.
(9) CPLT - The calibration results are plotted on a CRT terminal to identify any receiver problems.
(10) TRPT - A hard copy of the CPLT plot is produced at a print terminal. These programs help staff to maintain the radar systems and are indispensable in day-to-day operations.

RADAR CALIBRATIONS

Vast volumes of digitized radar data have been accumulated in the past few years. These data have been extensively used in research on storm structure, intensity, and motion, and on hydrometeor identification. To ensure precision in the analysis of the data, it is imperative that the radars be calibrated. Radar calibration consists of receiver calibrations, computation of the radar constant, correction for range, and calibrations of the azimuth and elevation indicators (Barge *et al.*, 1976).

Receiver Calibrations

To calibrate the radar receivers, a signal of known frequency and power is injected into the receivers. This signal is range-integrated and digitized, as are the received radar signals. The phase detection circuit is calibrated by using a remote signal source called the monitor which can transmit signals of linear or circular polarization. The monitor is mounted on a 90-foot (22-m) tower located 1300 feet (396 m) from the S-band radar. It can also be used to test the polarization characteristics of the S-band antenna. A phase shifter is used to simulate phase changes, and the results are recorded in the computer. A calibration program stores the data values in calibration files which are assigned to the data tapes of the corresponding day, to allow calculation of reflectivities. Other programs are used to graphically display the contents of the calibration files and produce paper copy graphs as required (Fig. 4). Calibrations are conducted at least once a day to determine the stability of the radars' receiving and recording systems, and the results are compared to those of the previous days to detect any significant differences. This way one is confident of the calculated reflectivities.

Radar Constants

The radar constant is used in the calculation of equivalent reflectivity values. It is dependent on antenna gain, wavelength, waveguide losses, and transmitted power (Barge *et al.*, 1976, Humphries *et al.*, 1977). Because of the day-to-day fluctuations in the transmitted power, a mean of the power level is obtained (with variance of 0.2 dB) and assigned to the corresponding data tapes in the calibration files. This ensures more accurate calculation of the radar reflectivities.

Radar Range

The radar ranges are derived from "range bin counting". There is some ambiguity in the 1974 and 1975 data because the range bins used were of uneven duration. This problem was resolved by referring the range integrator clock to a stable, high frequency master oscillator. Each range bin is 7.0 μs wide which is equivalent to a range-averaging interval of 1.05 km. Range measurements are calibrated by observing the distance of known landmarks such as Netook microwave tower (21.9 miles (35.3 km)) and Limestone Mountain (67.0 miles (108 km)). The location of these references, as determined from the digital radar data, were well within the accuracy of measurements (0.8 km) made from maps (Barge *et al.*, 1976).

Radar Azimuth and Elevation

Antenna azimuth and elevation angles are determined by synchros, devices used for the electrical transmission of angular position.

The electrical signals from these synchros are digitized into 14 bit data (resolution of 0.022°) by synchro to digital converters. These are stored together with the received radar echoes as part of the header information on the magnetic tapes (Barge *et al.*, 1976). The azimuths of the radar antenna are calibrated by referring to echoes from known landmarks (Netook tower at 200.6° and Limestone Mountain at 256.5°). In other experiments, transponders and bi-directional transmissions using signal sources at Gilbey Hill (319.6° azimuth and 24.14 mi (38.9 km)) were used to calibrate the azimuths of all three radars. It was concluded that the azimuths of the three radars are accurate to better than 0.2°.

It is not quite as easy to calibrate the elevation of the antennas. Until recently, mechanical levels were used to roughly level the antennas. Antenna alignments using the sun and standard target tracking methods are now being pursued. Preliminary results show that the measured elevation angles are accurate to within 0.1 degree.

RADAR DATA APPLICATIONS

A radar is capable of generating an enormous amount of data at tremendous rates. The AHP S-band radar, for example, produces per radar pulse four channels of 8-bit data in 147 range bins. For each radar pulse, the data in

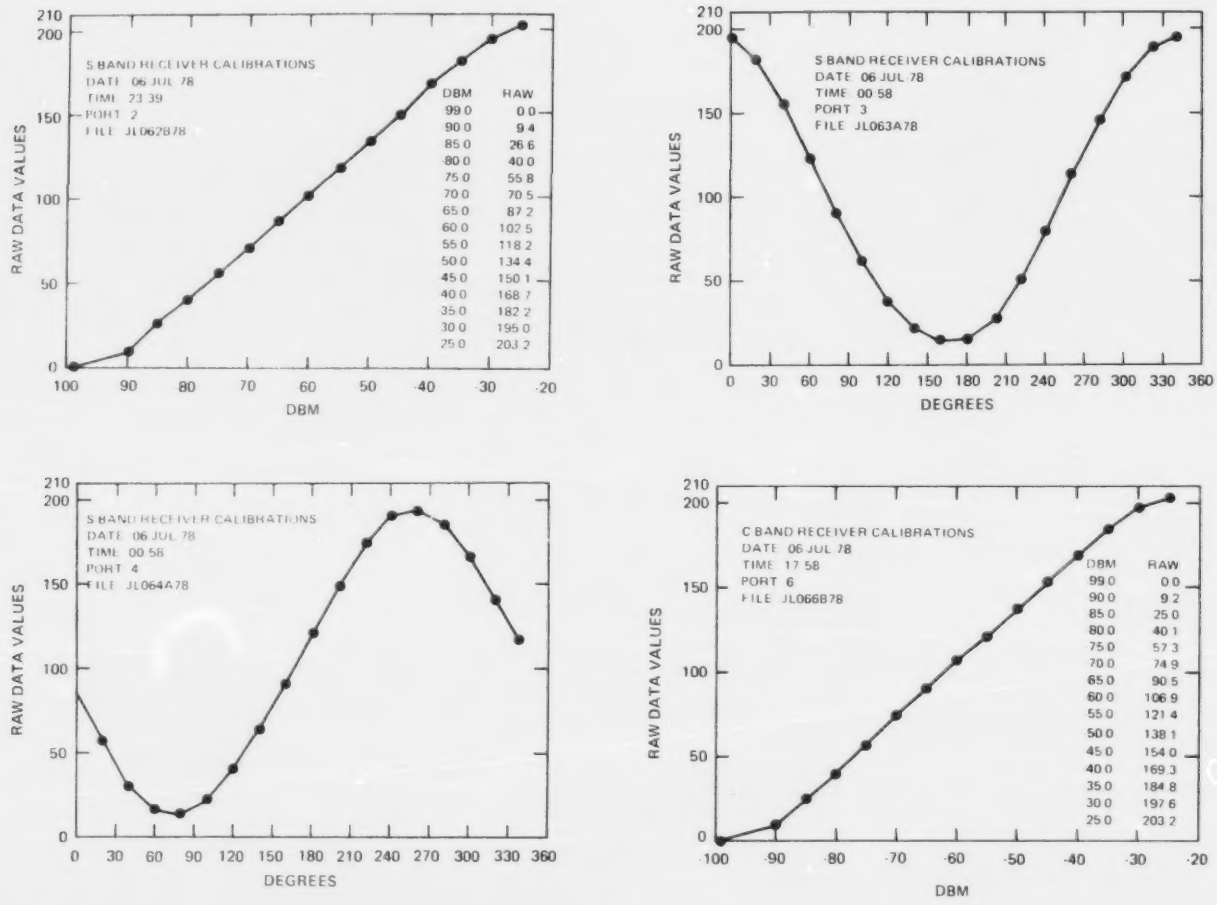


FIGURE 4. Radar receiver calibrations

each channel is referred to as a ray. This represents an instantaneous data production rate of 4.57 million bits per second! Azimuth-averaging is used to reduce the radar data to 7 bits at 14 thousand words per second (each word is composed of two data channels of 14 bits and two flags). The data are directed to the computer through a direct memory access (DMA) interface.

The computer compresses the data by discarding the data words when the main component data value is zero. To retain the range information, range bin numbers called "pointers" are stored before contiguous sequences of non-zero data words. A header containing information about the antenna position and time of day is also placed at the beginning of each compressed ray of data. The data are accumulated in memory buffers, then stored on magnetic tapes (Barge *et al.*, 1976).

The number of computer tapes collected so far is summarized in table 1.

The increases in 1977 were due to routine daily recording, and in 1978 increases were due to 24-hour recording (section on radar operations).

Table 1.
Computer Data Tapes Collected

Year	Radar	Tapes	Hours	Days
74	CB	54	100	16
75	SB	157	260	44
	CB	6	13	3
76	SB	180	250	36
77	SB	438	690	83
	CB	9	17	8
78	SB	534	858	91
	CB	114	759	70

Film data are also available as a backup for these computer tapes. The amount of film taken is summarized in table 2.

The radar data tapes obtained are processed by various programs.

Routine Processing

The radar tapes are first duplicated to prevent accidental destruction, then processed to produce the following:

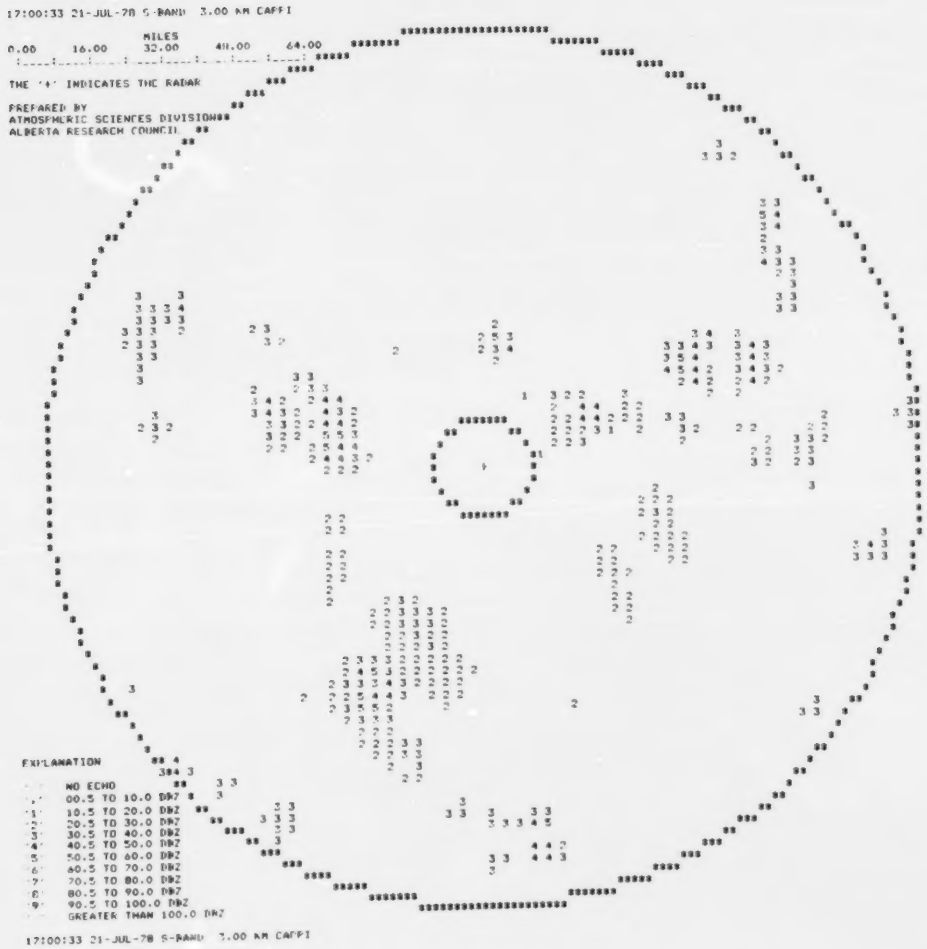


FIGURE 5. A CAPPI map

Table 2.

Amount of Film Taken

Year	Data	1000 Feet	Days
74	CB	5	35
75	CB	5	9
	SB	12	53
	CDR	5	22
76	CB	5	15
	SB	17	63
	CDR	14	52
77	CB	1	1
	SB	11	52
	CDR	7	40
78	CB	1	6
	SB	15	71

(1) Constant Altitude PPI (CAPPI) tapes are extracted from the slant range PPI data (Folliott *et al.*, 1979). The CAPPI data provide horizontal profiles of storms, which are easier to use in cloud physics studies. A typical CAPPI map is shown in figure 5.

(2) Hourly radar reflectivity summaries are produced from CAPPI data tapes to provide a quick resume of storm activities. These are useful in determining radar tape contents and selection of case studies. A radar summary map is similar to a CAPPI map, as shown in figure 5. 1.4.1.1.

(3) Maps of maximum radar reflectivity are printed daily to assist in deciding areas for telephone hail surveys. A map of maximum reflectivities is shown in figure 6.

(4) Maps showing accumulated rainfall were printed for the Flow Forecast Branch of Alberta Environment together with tables showing rainfall amounts in various river basins (Fig. 7). These maps are used with rain gauge measurements to forecast stream flow and flood hazard (Barge *et al.*, 1978). Because of the spatial varia-

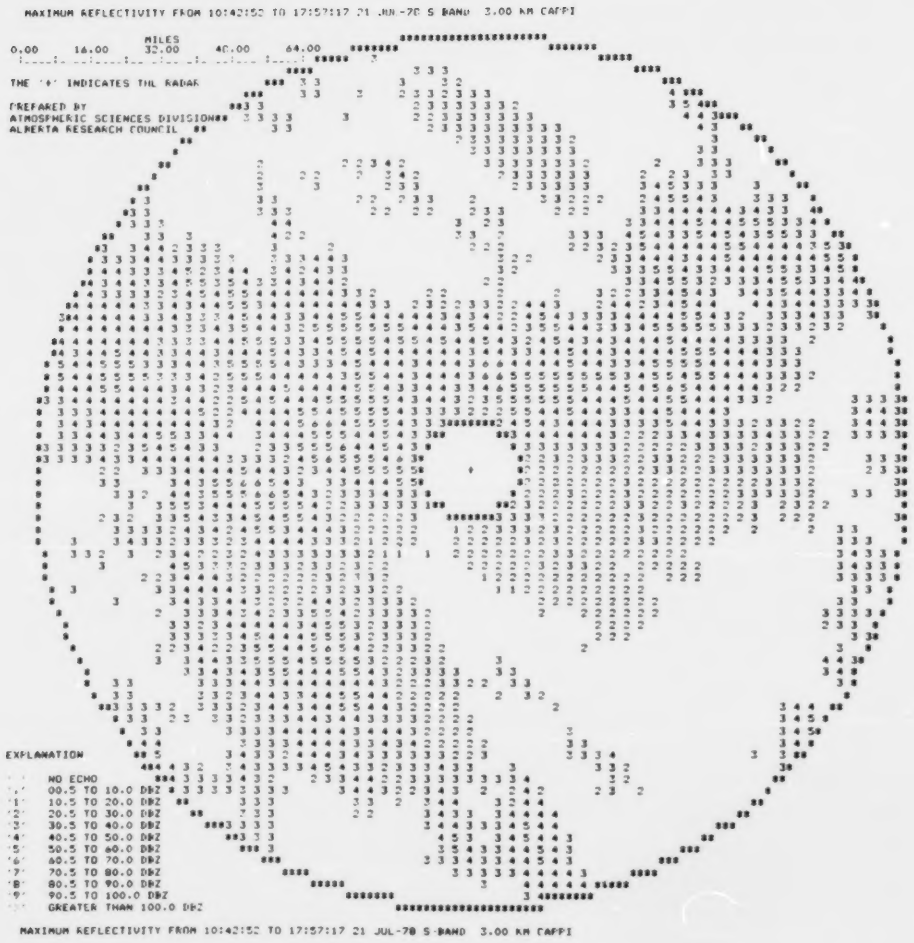

MAXIMUM REFLECTIVITY FROM 10:42:52 TO 17:57:17 21 JUL-78 S BAND 3.00 KM CAPPI
MILES
0.00 16.00 32.00 48.00 64.00
THE '+' INDICATES THE RADAR
PREPARED BY
ATMOSPHERIC SCIENCES DIVISION
ALBERTA RESEARCH COUNCIL
EXPLANATION
' ' NO ECHO
',' 00.5 TO 10.0 DBZ
'1' 10.5 TO 20.0 DBZ
'2' 20.5 TO 30.0 DBZ
'3' 30.5 TO 40.0 DBZ
'4' 40.5 TO 50.0 DBZ
'5' 50.5 TO 60.0 DBZ
'6' 60.5 TO 70.0 DBZ
'7' 70.5 TO 80.0 DBZ
'8' 80.5 TO 90.0 DBZ
'9' 90.5 TO 100.0 DBZ
'*' GREATER THAN 100.0 DBZ
MAXIMUM REFLECTIVITY FROM 10:42:52 TO 17:57:17 21 JUL-78 S-BAND 3.00 KM CAPPI

FIGURE 6. A maximum radar reflectivity map

bility of rainfall and the low density of gauges in most gauge networks, areal rainfall amounts derived from rain gauges alone are often unreliable. Radar has the advantage that it can scan large areas and thus measure the areal rainfall more accurately than a gauge network.

Post-Facto Analysis

Easy-to-use methods for retrieving and analyzing the recorded data are essential. In the AHP this is achieved through an interactive graphics program called BIRDD (Basic Interactive Radar Data Display). This program displays the data in the conventional PPI format on a storage CRT with zoom features that can display the echoes in considerable detail (Fig. 8). The analyst is able to extract any data for numerical processing and produce permanent copies of the display as desired. The program is so easy to operate that it can be used by anyone after a few minutes of instruction. The analyst is not required to type in instructions as these are displayed as a menu and a cursor is used to select commands.

This interactive display program is a powerful tool essential in the analysis of radar data (Ramsden *et al.*, 1976; Ramsden *et al.*, volume II).

Real-Time Display

The real-time display is very similar to the BIRDD. It is used by aircraft controllers to direct seeding operations. Up to 8 aircraft can be monitored simultaneously with continuous aircraft position updates while the storm echoes are held on the storage CRT. Using the zoom feature, analysts are able to display the echoes in great detail, and the aircraft cn be directed to precise seeding locations. An example is shown in figure 9. Other useful options include the hail detector (Barge, 1974), navigational aids, and block airspace maps.

The real-time display is so flexible and easy to use that it has become indispensable to the aircraft controllers (Humphries *et al.*, 1978; Humphries *et al.*, volume II).

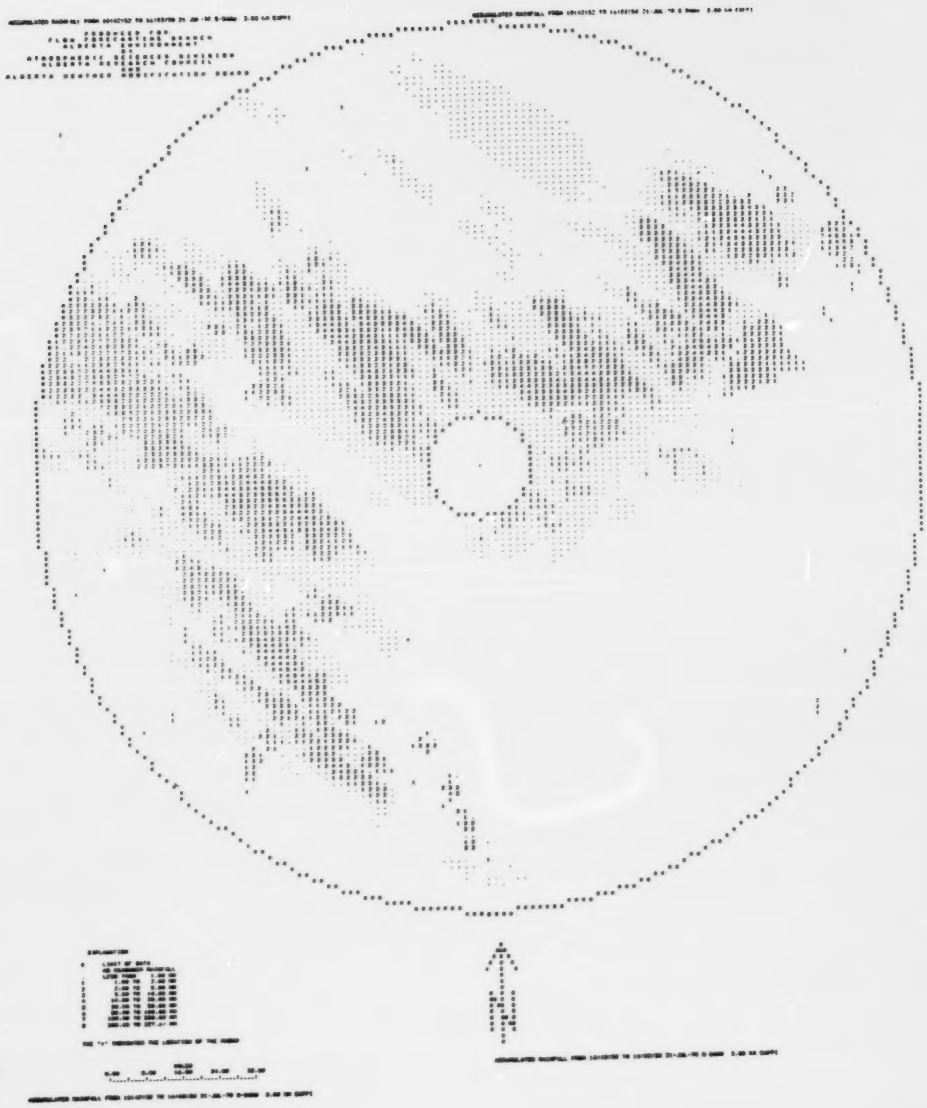


FIGURE 7. A rainfall map

DESCRIPTION OF SELECTED MAJOR DESIGNS

Many new designs have been incorporated into the radar systems in the past few years. The more important advances are described in the following subsections.

RANGE INTEGRATOR, 1974-1976

The range integrators are used to average the received radar signals over a range of interval of about 1 km in length. The radar video signal is typically noisy and fluctuating with an instantaneous value that can vary over a wide range (Marshall, 1971). Range averaging produces a more stable signal, which represents the storm intensity more closely. The area of the radar video envelope over a 7.0 μs interval (1 km in radar range) is calculated through integration according to:

$$V_{op} = V_{os} + G \int V_{ip}\, dt$$

where V_{op} = integrator output voltage
G = integrator gain
V_{ip} = integrator input voltage
dt = integration period = 7.0 μs
V_{os} = offset voltage

This is depicted in figure 10.

The integrators are represented by a block diagram in figure 11. In fact, two integrators and sample-and-hold circuits process the radar video signal from each logarithmic amplifier. After each integration period the output voltage is stored by the sample-and-hold circuit while the integration capacitor is discharged. Thus two integrators alternate in action and the output is delayed by one range bin. Analog MOS (metal oxide semiconductor) switches

Table 3.

Hourly rainfall accumulations for various river basins

21-JUL-78 S-BAND 3.00 KM CAPPI HOURLY ACCUMULATIONS BY BASINS (MM)

FROM:		10:43	11:01	12:00	13:02	14:01	15:01	16:04	17:01
TO:		11:01	12:00	13:02	14:01	15:01	16:04	17:01	17:54
INTERVAL:		00:18	01:00	01:01	01:00	01:00	01:03	00:57	00:54
ACCUMULATED:		00:18	01:00	01:01	01:00	01:00	00:33	00:57	00:54
BASIN SUB-BASIN	AREA (KM²)								
BOW RIVER BASIN									
WA01	335.79	0.00	0.00	0.00	0.06	0.05	0.20	0.04	0.00
JP01	527.20	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.08
BASIN MEAN	862.98	0.00	0.00	0.00	0.02	0.03	0.08	0.03	0.05
NORTH SASKATCHEWAN RIVER BASIN									
CW01	1020.35	0.00	0.00	0.00	0.01	0.06	0.01	0.00	0.00
CW02	1926.98	0.00	0.00	0.03	0.25	0.94	0.72	0.16	0.02
BASIN MEAN	2947.32	0.00	0.00	0.02	0.17	0.63	0.47	0.10	0.01
RED DEER RIVER BASIN									
RD01	743.50	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
RD02	757.55	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.01
BT01	338.21	0.00	0.00	0.00	0.02	0.38	0.01	0.01	0.00
JA01	824.18	0.00	0.00	0.00	0.06	0.64	0.76	0.14	0.00
BB01	289.85	0.00	0.00	0.00	0.00	0.04	0.03	0.21	0.00
RA01	588.78	0.00	0.00	0.00	0.07	0.25	1.18	0.08	0.32
ME01	1875.22	0.01	0.04	0.00	0.70	1.09	0.01	0.54	0.37
LR01	501.44	0.00	0.00	0.00	0.03	0.66	1.53	0.66	0.01
LR02	2023.14	0.00	0.00	0.00	0.01	0.01	0.02	1.20	0.38
BASIN MEAN	7941.87	0.00	0.01	0.00	0.19	0.41	0.27	0.50	0.21
BATTLE RIVER BASIN									
BA01	1874.65	0.00	0.00	0.00	0.03	0.20	0.05	0.09	0.52
PP01	568.84	0.00	0.00	0.00	0.01	0.06	0.00	0.00	0.00
BA02	4705.12	0.00	0.00	0.00	0.01	0.50	0.47	0.08	0.11
??01	469.88	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
BASIN MEAN	7618.49	0.00	0.00	0.00	0.01	0.36	0.30	0.07	0.20
RAIN GAUGE STATIONS									
GH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00
EB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

control the signal path through the integrators and the sample-and-hold circuits. These switches are selected by timing signals derived from a clock signal which is obtained by binary division from a stable, high frequency oscillator. This oscillator also serves as the timebase for the range ring generator and the trigger generator. (The system trigger initiates each radar pulse).

The output from the integrator is supplied to both the computer through the radar computer interfacing circuitry, and the PPI's through video processing circuitry. The processed video signal is them amplified before presentation on the PPI's.

AZIMUTH INTEGRATOR 1977

The azimuth integrators are designed to average further the radar returns. Previous to 1977 this process was done with computer software. The integrators are used to add the data from the same range bin for one degree of azimuth (equivalent to 10 radar pulses for the S-band and 16 for the C-band due to the different antenna speeds). The outputs are truncated before being sent to the computer. Hence the computer is only required to compress and format the data for the tape drives.

A block diagram of the azimuth integrator is shown in figure 12. A 12-bit adder is used to add the data stored in the random-access memory (RAM), and tri-state logic controls the flow of data to the RAM and output to the first-in, first-out (FIFO) memory buffer. For the first system trigger, zeroes are supplied to the adder and incoming data are stored in the appropriate RAM locations. After the programmed number of system triggers, the results of the summation are shifted out to the FIFO buffers. The buffer and multiplexer sequences the data words for the DMA (direct memory access) interface. The four azimuth integrators (one for each of the four S-band radar channels) are controlled by a common logic card. The C-band radar has its own azimuth integrator FIFO, memory buffer, and multiplexer, which could be made capable of handling four channels.

The integrators were installed in 1977, greatly reducing the computer CPU (central processing unit) time required for data recording. Thus more time was available for processing major programs like the real-time display.

AIRCRAFT TRACKING UNIT, 1975-1976

The aircraft tracking unit (ATU) was first used in 1975. It is a digital system designed to display on PPI's the aircraft

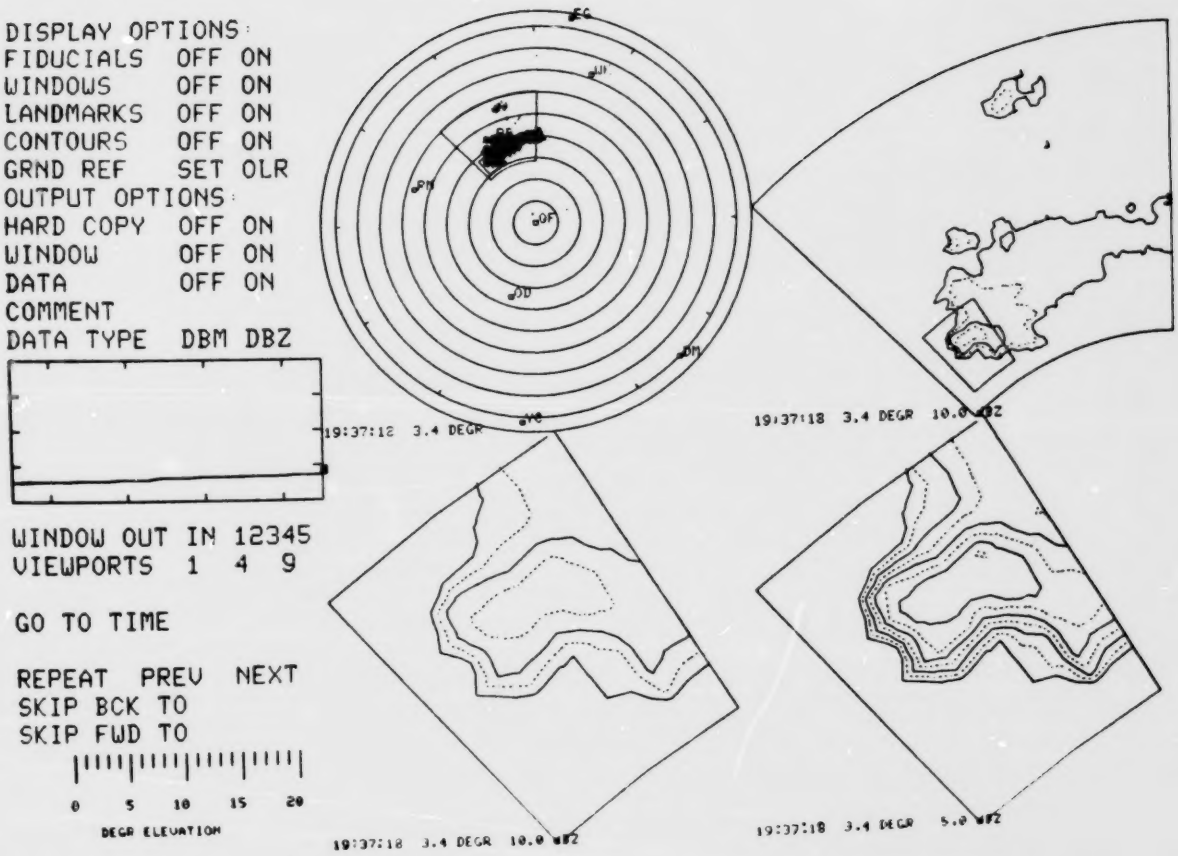


FIGURE 8. A BIRDD display

position information in proper registration with the selected weather radar (called the "reference" radar) echoes, while the two antennas rotate independently. The aircraft tracking radar video signal is decoded, and when an aircraft is positively identified, its position (azimuth angle of the tracking radar, and range) is stored. This information is compared to the weather radar azimuth and range; when these agree the aircraft position is displayed on the PPI's. A secondary function of the ATU is to supply antenna and aircraft position information to the computer (section on radar/computer interfaces).

A block diagram of the ATU is shown in figure 13. There are four synchro-signals which are digitized by synchro to digital converters (SDC) into 14-bit data representing position accurate to 0.022 degrees. The ATU utilizes the "shared bus" principle for data transfer whereby the data from the four input signals are transferred by common circuits through a time sharing arrangement (called multiplexing). Each SDC data update initiates both a polling to identify the source and an electronic circuit to transfer the data to a memory internal to the ATU and to an interface which stores the data until requested by the computer. Weather radar azimuth updates are followed by a comparison of the new azimuth data from the weather radar to the stored aircraft azimuth data. A positive response starts the range comparators and coded pulses are supplied to the PPI's to indicate aircraft positions. The aircraft position latches are then cleared to await new information.

The weather radar can be selected from either the S-band or the C-band by switching the lines from the azimuth synchros and the digitized angles can be monitored through light emitting diodes. Also associated with the ATU is the aircraft simulator. This supplies simulated aircraft transponder replies to the ATU aircraft decoder in order to test the ATU.

The ATU provides accurate and reliable aircraft position displays on PPI's. Such information is indispensable in controlling seeding operations. The aircraft positions are also recorded by the computer and shown on the real-time display. Because the real-time information is displayed on a storage tube, aircraft tracks relative to the position of a storm can be easily determined.

PHASE DETECTION CIRCUITRY, 1977

The phase detection circuitry determines the phase difference and electrical correlation between the port 1 (main) and port 2 (orthogonal) signals. This difference reflects the depolarizing characteristics of the precipita-

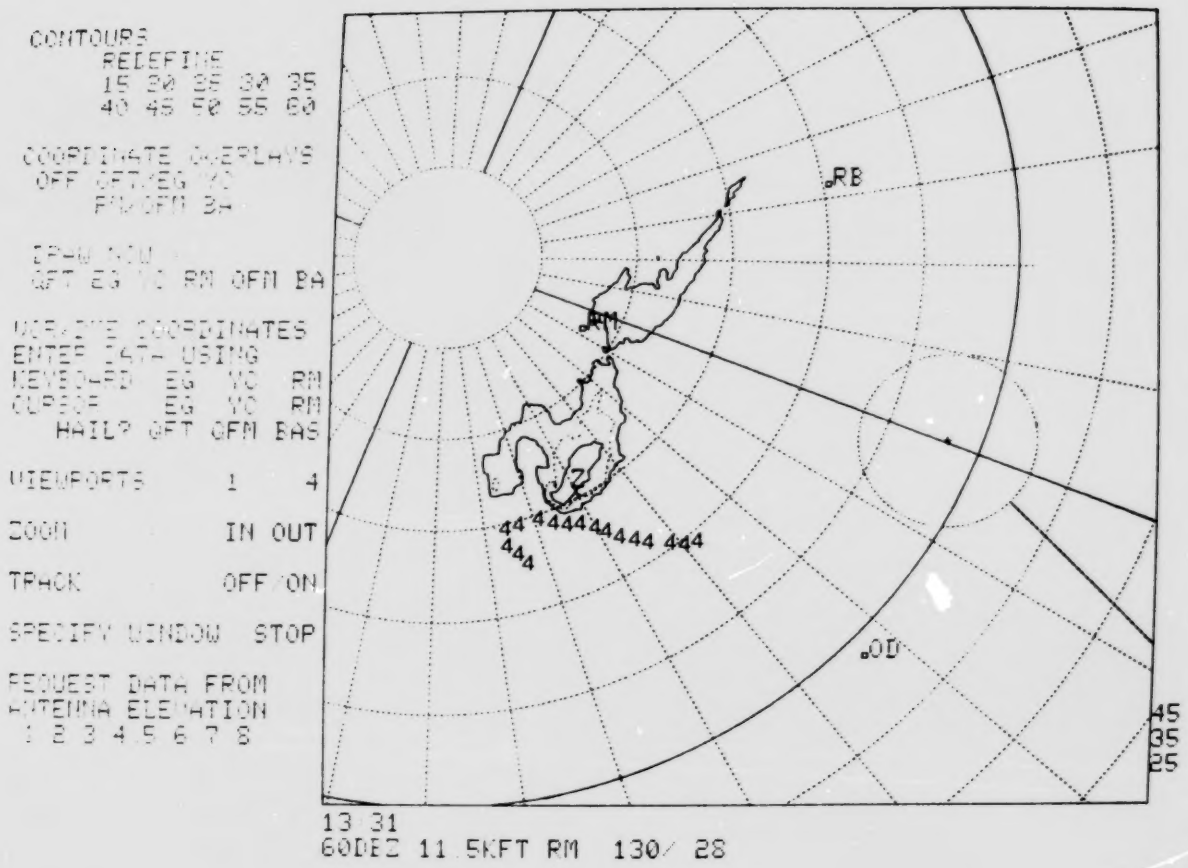


FIGURE 9. An interactive real time radar display

tion and indicates the preferred orientation of the particles in a storm. Large rain drops have a preferred horizontal orientation, but hailstones have more random orientation which produces a noisy phase signal (Hendry *et al.,* 1976).

A block diagram of the phase detection circuitry is shown in figure 14. The step attenuators allow adjustment of the dynamic ranges and the limiters provide signals of constant amplitude. The phase difference between the two signals is obtained from the phase detectors whose outputs are proportional to the sinusoidal function of the phase angle. There are two channels, one with an additional 90 degrees phase shift, producing a sine and a cosine function from which the phase difference can be calculated unambiguously. The outputs from the phase detectors are range-integrated over 1 km. The results are digitized, azimuth-integrated, and recorded by the computer (Leung *et al.,* 1976).

The preliminary analysis of the phase data has yielded promising results; the identification of hydrometeor types within hailstorms should become easier (Barge and Humphries, volume II).

RADAR/COMPUTER INTERFACES, 1974-1977

The function of the radar/computer interfaces is to supply the computer with the radar-derived information. The

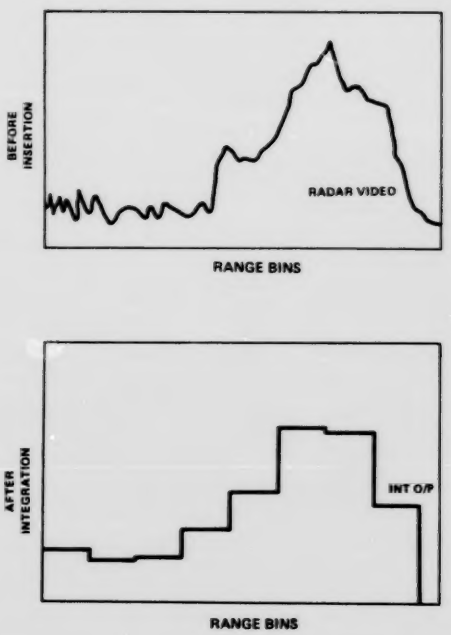


FIGURE 10. Range integration of a radar video signal

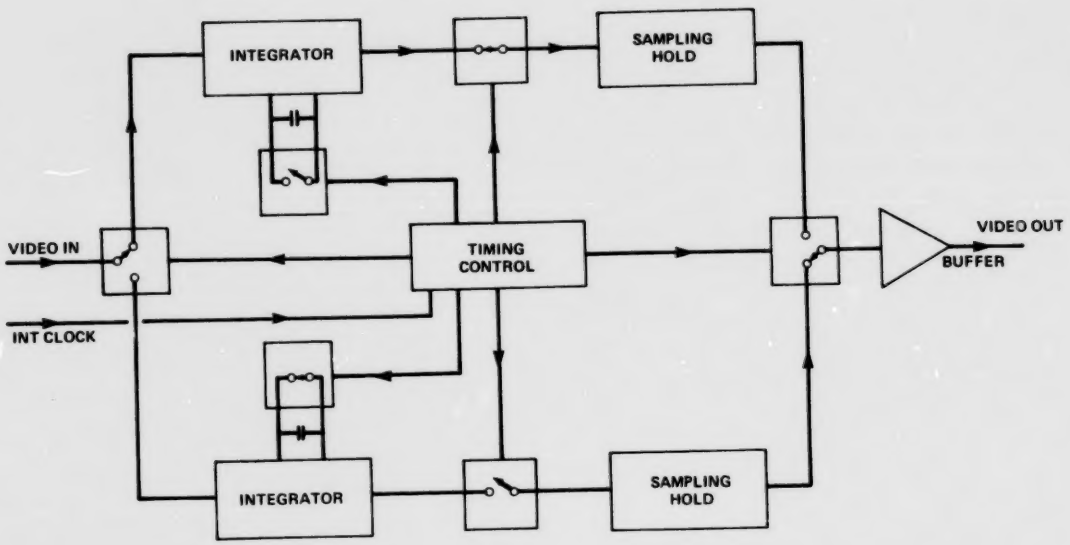


FIGURE 11. Block diagram of the range integrators

computer must record four video signals from the S-band radar, one video signal from the C-band, two synchro signals (for azimuth and elevation) from each of the two weather radars, one azimuth signal from the X-band, and eight pairs (azimuth and range) of aircraft position data.

The video signals require special attention because of the fast data rate. The four S-band video signals are digitized into 8-bit binary numbers and arranged into two 16-bit words. There are 147 range bins (7.0 μs) per radar system trigger at 478 Hz PRF (pulse repetition frequency). This represents a recording distance to 150 km with the data from the first three range bins discarded because of ground clutter contamination. Prior to 1977 the computer was required to average the data from ten system triggers and compress and format the data for the tape drives. Because of the high input rate little time is left for the CPU (central processor unit) to do other tasks. The situation improved in 1977 when integrators external to the computer did the averaging (see section on azimuth integrators).

The video radar interfaces are shown in figure 15. The digitized video signals are inputted to the computer through a direct memory access (DMA) interface. The data are directly deposited into specified memory locations by the DMA. A first in-first out (FIFO) memory buffer was designed in 1976 for the DMA interface to ease any computer timing problems. The C-band video interface is identical to the S-band except there is only one channel.

The information on antenna and aircraft positions is supplied to the computer through part of the aircraft tracking unit (ATU). The ATU, radar azimuth and elevation, and aircraft information interfaces are depicted in figure 16. The data which are stored at peripheral memory locations are collected as required by the computer. The ATU can transmit only four channels of azimuth and elevation information. Consequently another channel was added in 1977 to record C-band elevation information.

The development of the computer recording capability is listed below:

1974	one channel C-band data with heading marker pulses (the heading marker is a switch that is closed when the radar rotates past a predetermined azimuth)
1975	two channel S-band data S-, C- and X-band azimuths selectable S- or C-band elevation 8 aircraft azimuths and ranges
1976	FIFO memory buffer added
1977	four channel S-band data one channel C-band data C-band elevation hardware azimuth integrators for both S- and C-bands.

RELIABILITY ANALYSIS

In the past five years much effort was made to improve the radar systems. The reliability of the radar systems received special attention because the radars were required to operate daily throughout the hail season (approximately 87 days each summer). To assess system performance, the system's reliability was analyzed.

The problems of the past five years are summarized in tables in appendix A. The data indicate that the overall reliability has indeed been improved. The total number of hardware breakdowns has apparently declined by over 50 percent in the past five years, although data from the early years are incomplete. The larger number of major failures in 1978 was due to a change in cataloging: problems with the C-band transmitter and computer are now added to

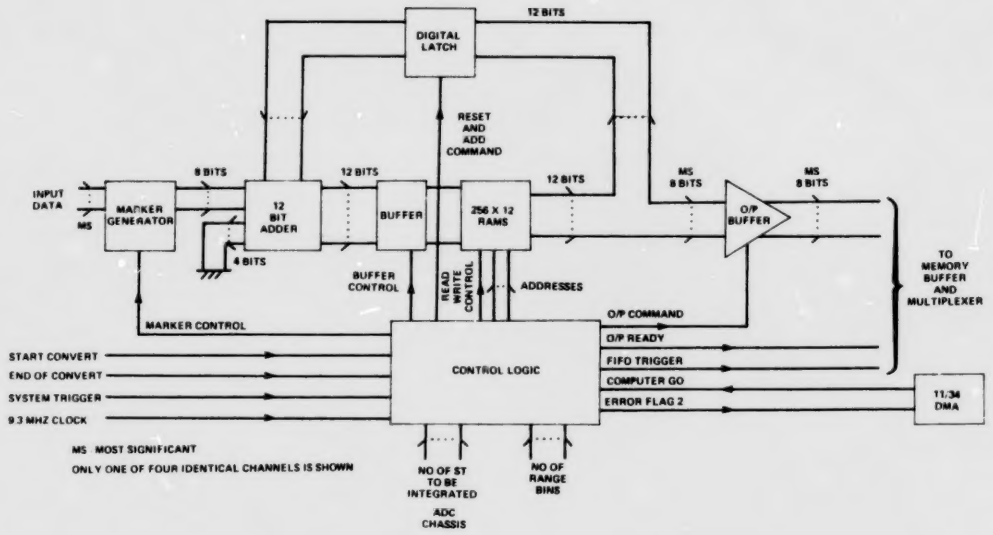


FIGURE 12. Block diagram of the azimuth integrator

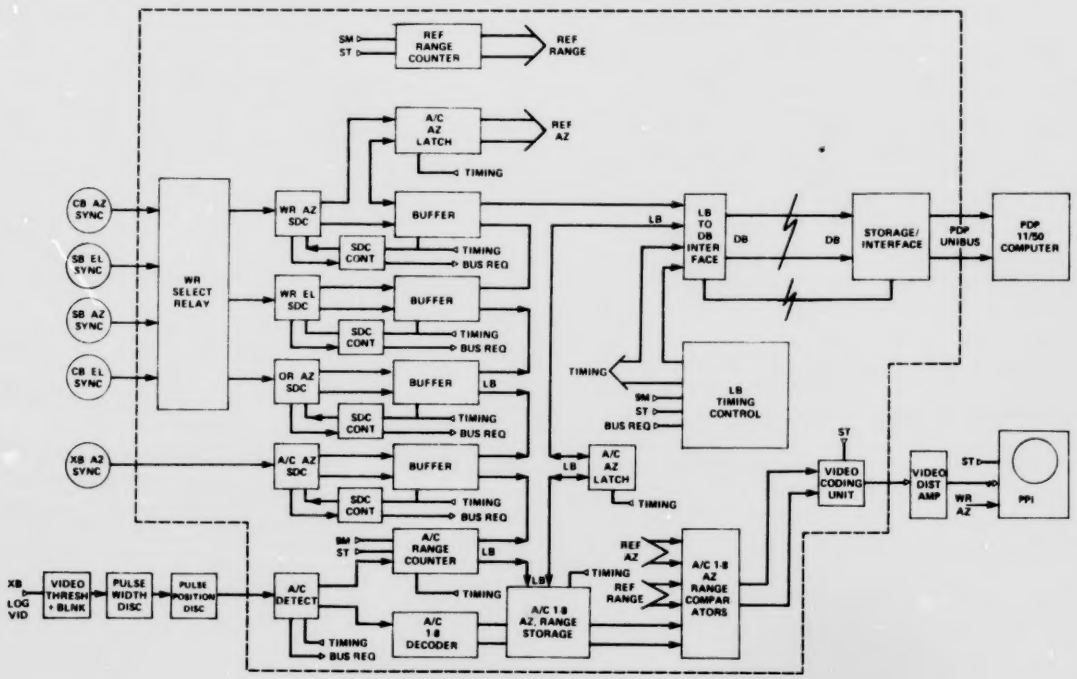


FIGURE 13. Block diagram of the aircraft tracking unit

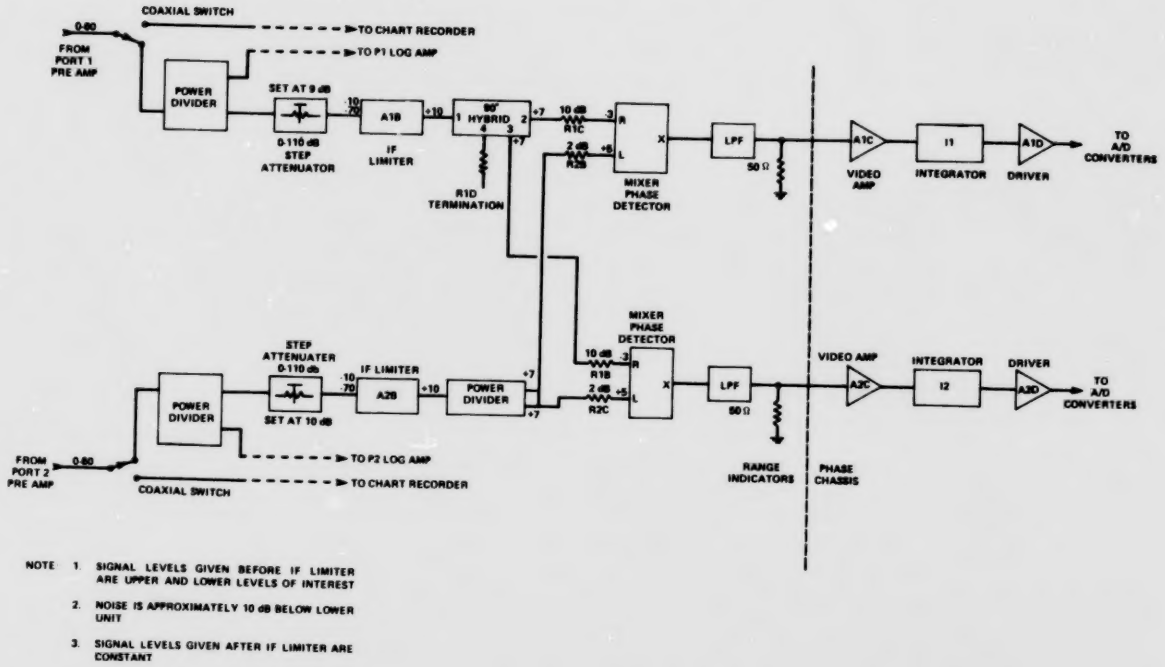


FIGURE 14. Block diagram of the phase chassis

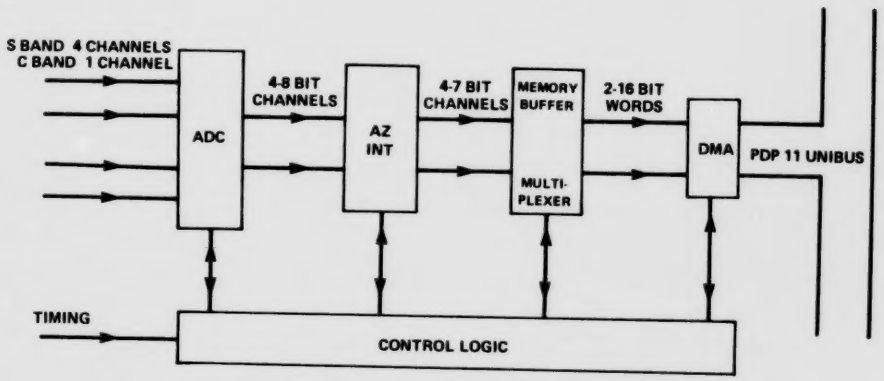


FIGURE 15. Block diagram of the video radar/computer interface

the list, but previously the C-band was used as standby only and computer problems were not entered into radar logs. The increase in major failures in 1977 was due to the use of the old S-band transmitter which had become unreliable and for which parts had become unavailable. We concluded, when these situations were accounted for that the radars are reliable in that the chance of a total system shutdown is very small.

Radar systems are only 100 percent reliable if completely duplicated, which is far too expensive. The weaknesses of the existing AHP radar/computer systems are in the critical equipment: failure of transmitters, antenna drives, or computer hardware can markedly reduce data collection and aircraft tracking capability. To reduce down-time, the radar section stocks crucial parts. The antenna drives are also inspected before and after each

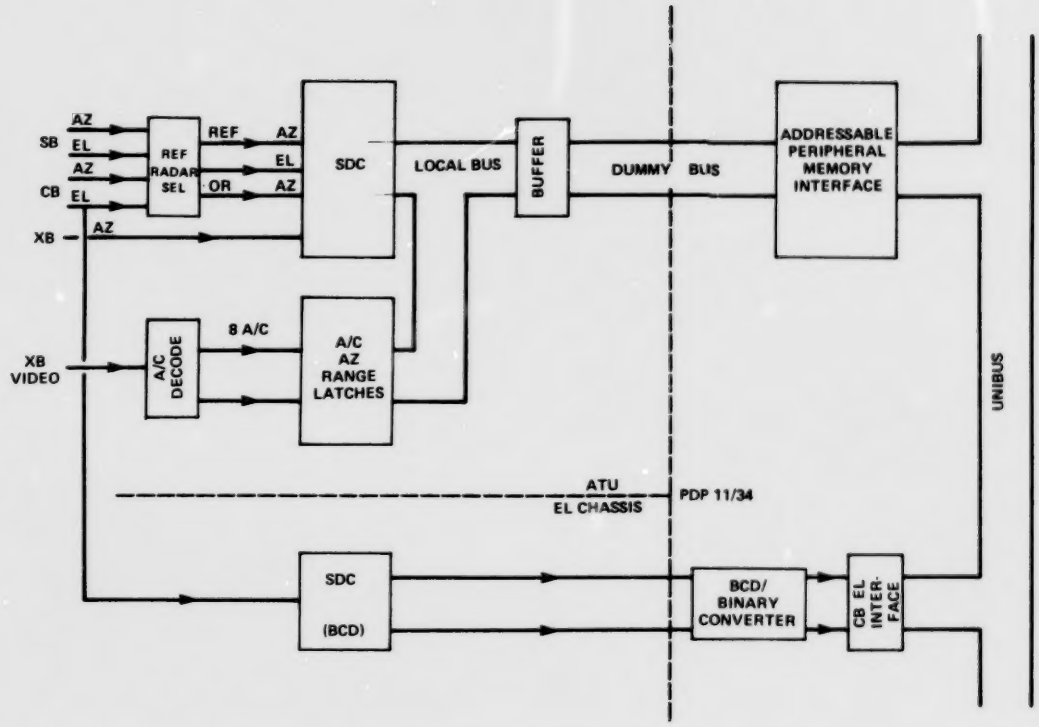


FIGURE 16. Block diagram of the synchro and aircraft radar computer interfaces

season and the transmitters' performances are monitored carefully for deterioration. The computer is maintained through 24-hour service contracts with the manufacturer.

Another factor is the highly unpredictable human factor. Operator errors, discovered in the analysis are:

(1) uncertain calibrations
(2) data panel for the camera-equipped PPI set incorrectly
(3) film cartridge mounted incorrectly
(4) monitor transmitter left on
(5) polarization incorrectly set
(6) personnel exposed to microwave energy
(7) equipment damaged from misuse
(8) attenuation left in port 1 after major calibrations
(9) computer tapes mounted incorrectly or too late.

To reduce operator errors, warning devices were designed and detailed operation routines and procedures were established. For example, to prevent personnel from being exposed to the transmitted radar microwave energy, warning lights and audio alarms were installed. As a result there were no such incidences of personnel exposure to microwave radiation in 1977 and 1978.

In recent years radar staff and summer assistants have diligently followed established procedures, so the number of operator errors has been substantially reduced.

SUGGESTIONS FOR THE FUTURE

The AHP radar systems are complex, powerful, and unique in North America. The radars have been improved to the extent that they are reliable and capable of meeting the operational and research requirements of the AHP. However, techniques to further improve systems' capabilities can be adopted. Some of these methods are discussed below.

(1) Ground clutter rejection — This could reduce number of computer tapes since ground echoes would not be recorded. Also the uncontaminated received radar signals could be much more easily analyzed.
(2) Color display — Some radar data, CDR (circular depolarization ratio) (Barge, 1974) in particular, are not easily displayed by using conventional display methods like contouring. Computer-generated color display can overcome this difficulty. Gray *et al.* (1975) proved that color displays can increase comprehension of radar data. Color displays, if available in AHP, would assist in the recognition of seeding situations.
(3) Automated calibration — This may reduce operator errors, calibration time, and manpower requirements.
(4) Polarization switching — When the polarization of the transmitted radar pulse is switched rapidly from LHC (left-hand circular) to RHC (right-hand circular) and back, additional

information concerning the distribution of hydrometeors can be obtained. The information available is the phase angle difference between the main and orthogonal components attributable to non-Rayleigh scatterers (Humphries, 1974). This information with other radar data, allows more complete identification of hydrometeor types and sizes.

(5) Doppler detection — Doppler shift detectors can be added to the present receiver systems to provide wind shear data. This may be useful in detecting severe radial wind conditions in storms.

(6) CAPPI elevation program — The resolution of the slant range radar data is about 1° in azimuth and 1 km in range. The slant range format requires that the actual height of the data be calculated using the radar range and elevation (Folliott, this volume). This poses problems for scientists, as horizontal profiles of the storm are desired. In 1978 CAPPI tapes were produced from slant range data tapes. Production of the CAPPI tapes was difficult due to the nature of the radar's elevation program. A special elevation program can be designed to facilitate straightforward production of the CAPPI's.

OPERATIONS AND RESEARCH

The AHP is unique in that it combines a seeding operation with a research program. A seeding program is often in conflict with a strict research experiment. For example, a seeding program requires that the radar be on continuously whereas the basis of research is often case studies. The differences between the two are compared in table 4 .

Table 4

Differences Between Research and Operations

Requirements	Research	Operations
Manpower	Less	More
Radars	Less	More
Calibrations	More	Less
Development	More	Less
Data Logging	Yes	No

A good balance has been maintained between research and operations in the AHP. The radars are operated routinely in surveillance scan mode with computer data logging. The receivers are calibrated daily and the transmitted powers are carefully monitored. New developments have improved data quality, operation capabilities, and system reliability. This way the requirements of both research and operations are met in the AHP.

Research is the basis of the operations technology and new findings have caused staff to alter the seeding strategy used in Alberta (Barge *et al.,* 1976). It is essential that research efforts not be sacrificed, for only through scientific studies can the mechanics of hailstorms and the effects of seeding be demonstrated.

SUMMARY

Progress has been made in using the radar data to distinguish hydrometeors in clouds. Polarization, dual-wavelength, and phase measurements have proved useful in determining the nature of hail formation. The aircraft-tracking capability and computer-generated real-time displays make seeding operations much easier. Radars are also used extensively to provide data for storm studies, hydrological studies, flood forecasting, and telephone surveys of the farm community after storms.

Over the past years there have been many technological advances in both the hardware and software in the AHP radar and computer systems. The staff are also now very experienced in the operation of radars interfaced to a computer. Thus, the AHP has developed one of the most advanced radar-computer systems in the world.

ACKNOWLEDGMENTS

We are grateful to the many people who contributed to the development of the AHP radar systems, especially L.E. Allan, A. Hendry, and G.C. McCormick of the National Research Council who are pioneers in the field of variable polarization radars. We are also indebted to P. Smith of the South Dakota School of Mines and Technology, who suggested the adoption of range integrators, and S. Hollemeyer of the ARC machine shop who helped to maintain the antenna drives.

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APPENDIX A
AN ANALYSIS OF SYSTEM RELIABILITY

The occurrences of system failures as entered in the radar logs were analyzed to produce this appendix. Table A. 1 contains a summary of the results of the analysis. It is necessary to clarify the terminology used in this table.

Event count - major: This is defined to be any loss of the S-band radar, C-band radar, aircraft displays, or the computer for more than ten minutes. A threshold of ten minutes is used so that computer crashes and common malfunctions of the transmitters would not be counted as majors. Those problems requiring a repair time of over two hours are considered to be more serious and are counted in a separate column.

Event count - minor: All other events not covered in the definition of major events are defined to be minor.

Event count - major effects on research: This is defined to be any total loss of aircraft or weather radar data as recorded by the computer.

Event count - minor effects on research: All other events not covered as having major effects are defined to have minor effects. Quality of computer data may be affected but can be improved with calibration.

Event count - major effects on operations: This is defined to be any total loss of weather radar echoes, aircraft displays (PPI or computer generated real-time), or communications during operations.

Event count - minor effects on operations: All other problems not covered as having major effects are defined to have minor effects. It must be stressed that these problems should affect operations only. For example, calibrations and camera data troubles have no operations effects.

Due to incomplete logs in the early years it is important to note the following:

(1) 1975 events include a conservative estimate of 300 resets of the real-time clock.

Table A.1.

Summary of System Failures, 1975 - 1978

Year	Event Count			Event Count of Effects on			
		Major		Research		Operations	
	Minor	Over 10 Min	Over 2 Hr	Minor	Major	Minor	Major
1975	558	30	2	507	63	400	62
1976	378	5	5	432	23	258	22
1977	268	17	5	279	92	165	77
1978	222	21	8	114	114	106	108

(2) The C-band events are considered to be minor prior to 1978 because of its use as a standby radar. In 1978 C-band data were recorded routinely, so that any C-band failure is now considered to be major.

(3) Computer problems are not included in the radar logs until 1978.

(4) Increases in 1977 in the number of major events are due to the unreliability of the old S-band transmitter.

(5) Some events affect both research and operations and consequently are entered into both columns.

Table A.2 contains the extracted data from the radar logs. Problems are listed with information on frequencies, effect, and time to repair.

Table A2

Extracted Data from Radar Logs

Problems	Frequency Per Year				Effects on Research		Effects on Operations		Time To Repair	Remarks
	75	76	77	78	Minor	Major	Minor	Major		
Enterprise transmitter down				1		x		x	Dec. 12 78 7 mo. later pulse package still under repair	
Enterprise transmitter tripped out		7	38	4		x		x	5 min to 1 day	Shorted wiring and relays
502 Radar										
Down				4		x		x	10 min to ½ hr each	
Tripped out	7			5					7 min	
Off frequency				9					5 min	
SB Antenna										
Damaged wave guide				1		x		x	6 hr	

Table A2 (continued)

Problems	Frequency Per Year 75	76	77	78	Effects on Research Operations Minor	Major	Minor	Major	Time To Repair	Remarks
Az drive				1		x		x	2 days	
Elevation sequence	18	9	10						5 min to 1 hr	
Tripped out	11	1	3	2		x		x	3 min	
X Band Tx & Rx										
Tx down				3		x		x	3 hr	Shorted transistor
Tripped out		2	1	2		x		x	5 min	
Tx off frequency	2	2	2	7	x		x		10 min	
Rx off frequency		4		6	x		x		10 min	
Antenna down		1		3		x		x	1 hr to 1 week	
TT1 threshold adjusted (noise)	1	13	11	1	x		x		10-15 min	
CB Tx & Rx										
Tx down	2	3	2	5*		x*		x*	1 day to 1 week	1978 replaced pulse package new one N S
Tripped out	9	14	48	9*	x	x*	x	x*	5 min	
AFC drift		3	4	4*	x	x*	x	x*	½ hr	
CB Antenna										
Elevation sequence	1	14	3	3	x		x		10 min to 1 hr	
Az drive motor			1	1*	x	x*	x	x*	1 week to 10 days	Replace drive motor
Rx crystals	2	4		2	x		x		5 min	
Rx off frequency			1						10 min	
***CB in 78 considered major**										
PPI's & Cameras										
Data panel malfunction	10	27	9	10	x		x			Replaced cord
Data panel set wrong	6	9	3		x		x		1 hr to 1 day OE	Keep in mind 1978 only one 35 mm camera was used
Camera out of film	7	9							1 min to 1 hr	OE
Film jammed in camera	11	16	10	1	x		x		10 min ½ hr	
Loaded wrong	2	7	5	2	x		x		5 min	
Film broke				10	x		x		5 min	10 film breaks were OE's
Film advance	6	1	2	0	x		x		½ to 1 hr	
Polaroid camera shutter	2	4	0	0					1 day to 2 weeks	Same camera all six times. Camera was replaced in 1976.
PPI video & sweep intensity	10	4	0	0	x		x		5 to 10min	Installed better controls.
Defective CRT	2	0	0	0	x		x		5 hr	Short in CRTS. Also burnt out video amps.
Defective power supply	1	0	1	0	x		x		1 hr	
Mixer box malfunction	5	4	0	0	x		x		1 hr	
Sweep alignment	7	5	0	0	x		x		1 day	Assembled wrong by EEC
Sweep blanking	0	0	1	0	x		x		1 hr to 1 day	
Syncro topigital converter	0	1	0	0	x		x		1 hr	
Heading marker malfunction	11	1			x		x			Redesign H.M. Chassis
Thresholds SB & CB	12			1	x		x		78 broken connector 1 hr	Redesign in winter of 75 76

Table A2 (continued)

Problems	Frequency Per Year 75	76	77	78	Effects on Research Operations Minor	Major	Minor	Major	Time To Repair	Remarks
Gray scale SB & CB	12	10			x		x		½ to 1 hr difficult to adjust subject to drift	Redesign winter of 76/77
Range rings	7	32	1						½ to 1 hr difficult to adjust subject to drift	Redesign winter of 76/77
Master Clock										
Reset itself to wrong time	300	48	4	15	x		x		1 min to ½ hr	Winter of 76/77 redesign and stabalized power supplies
									Note:	78 a series of electrical storms and power failures resulted in resets
Stopped	1				x		x		≈1 hr	Component failure
Remote readout down	2		4	1					≈½ hr	Component failure tube burnt out
11:00 HR CBC TIME CHECKS SHOWS CLOCK TO BE ACCURATE TO WITHIN 2 SEC. OVER ENTIRE OPERATIONS PERIOD (1978)										
Equipment failures										
X band generator		1	1	1	x		x		1 to 2 mo.	
C band generator		1		1	x		x		1 to 2 mo.	
S band generator	1			1	x		x		4 weeks	
Function generator		1	2		x		x		1 day to 4 weeks	
Power meter	2	5		1	x		x		1 day to 2 mo.	Mostly burnt out power heads (78 was a bad year for equipment failures; however having back up units in most cases avoided serious problems)
Frequency counter				1	x		x		4 weeks	
Spectrum analyzer			2	1	x		x		6-12 weeks	
Scopes	1	1	2	1	x		x		1 to 2 mo.	
HP frequency cavity					x		x		≈4 weeks	
Computer & Interface	5	4	6	4		x		x	1 day to 1 mo.	
Interface hardware	—	—	—	4	x		x		1 day to 3 weeks	
MTD down	—	—	—	6	x		x		1 day to 3 weeks	
MDI down			15	17		x		x	1 day to 3 weeks	
Logging down or malfunction			4						½ to 1 day	
Hard copy program down			2						½ to 1 day	
Flow program down			19	1		x		x	3 days	
CPU down				14		x		x	5 to 10 min	
Crashes				6		x		x	½ hr to 1 mo.	
Real time display down										
ATU & transponders		2	2		x		x		1 to 2 mo.	Serviced by Motorola
Defective transponders		3				x		x	1 day week	
ATU down				2		x		x	1 min to 1 day	OE
ATU reference switch set wrong										

Table A2 (continued)

Problems	Frequency Per Year 75	76	77	78	Effects on Research Operations Minor	Major	Minor	Major	Time To Repair	Remarks
A/C ring around										Solved in 78 by using STC
A/C stuck bit, displaced		11		2						Design faults
A/C, Bogus A/C										Debuged ATU
A/C 4, 8 dropping out				1	x		x		1 hr	Replace defective
A/C changing conds										temp drift cool room with air conditioner

Problems	Frequency Per Year 75	76	77	78	Effects on Research Operations Minor	Major	Minor	Major	Time To Repair	Remarks
Radios										
AM1	75, 76 design new system									
AM2	debug new system									
FM										
FM repeater down		1	1	1	At present there is interference from other aircraft					
AM1 down		1	1		and the Red Deer airport control tower. Could change					
AM2 down		1	1		frequencies or install antenna filters. To change to a					
					different type of transmitter and receiver could mean					
					extensive reworking of the radio communications sysem.					

DATA PROCESSING IN THE ALBERTA HAIL PROJECT

M.R. Johnson

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DATA PROCESSING IN THE ALBERTA HAIL PROJECT

M.R. Johnson

INTRODUCTION

The computing group within the Atmospheric Sciences Department (ASD) of the Alberta Research Council (ARC) is a computing service organization, providing software and hardware support for operations and research projects as well as general-purpose support for computer program development.

The overall goal of the computing group has been to provide easy access to data collected by the Alberta Hail Project (AHP), regardless of the computer expertise of its users. This approach has proven successful for scientists, technicians, and programmers.

The ARC computing group operates two computers, a PDP-11/50 based data analysis system, and a PDP-11/34 based real-time data collection system. Details of the computer-related equipment are given in the section on hardware. Both of the computer systems run the RSX-11M real-time operating system, with support software developed at ARC, described in the section on general purpose programs.

SPECIFIC PROJECTS

The major use of the AHP computer systems is to provide support for operations and research associated with the AHP radars. Primary among these is radar data collection, display, and processing. This computer support is described fully in the section on radar (J. Ramsden *et al.*).

GENERAL-PURPOSE SUPPORT

Any of the data processing done on the AHP computer systems is based on program development, so an effort has been made to provide an easy-to-use system for program development. Utility programs, user-oriented documentation, and operating system enhancements have contributed to making the computer systems easy to use. This software is described in the section on general-purpose programs.

RADAR

The Alberta Hail Project Radar system is capable of detailed observation of a large three-dimensional space centered at Penhold. To be useful for operational or research purposes, the information from the radars must be accurate, reliable, and easy to use. The conventional recording method (film photography) was unable to meet these requirements, so a minicomputer based digital system was installed. The evaluation of minicomputer systems is described in the section on hardware and the hardware interface providing digital data from the radar systems to the computer is described in the contribution from the radar group.

To ensure the accuracy of the digitally recorded data, routine calibration procedures were established; reliability was achieved with the data collection system; and ease of use was provided by the real-time and analysis systems.

CALIBRATION

Daily calibrations of the AHP C-band and S-band radar systems are performed using interactive calibration programs which simulate the familiar A-scope display for the power channels, and a phase diagram for the phase channels. These programs automatically lead the user through the calibration procedure, and supply a visual confirmation of their successful operation.

The resulting calibration information is printed for permanent reference and comparison with previous data, and recorded on disk and tape to be used when the data is analyzed.

COLLECTION

Integration

Data is collected from two or four channels of the S-band receiver system, or from the single C-band receiver channel. The data is produced by the radar systems in "sweeps", which represent the returned signal from one radar transmitter pulse. This returned signal is integrated by the radar hardware in seven microsecond intervals, producing 150 discrete values per channel (bins), which represents the usable range of the radar (approximately 150 km).

Integration is performed on each range bin individually, and separately for each channel of data. Data from each range bin of a number of sweeps (currently 10) are summed, then reduced to the desired accuracy by discarding all but the seven most significant bits of the sum. Until 1977, this range integration was performed by the computer system, using a highly optimized program running in special high-speed memory. The computer's operating system was modified to allow the fast response time necessary for this integration.

In 1977, the radar group installed a hardware azimuth integrator, which performed the same function as the computer program. This means that there are no data transferred to the computer until the integration is completed, thus reducing the average data rate to the computer by a factor equal to the number of sweeps integrated. Because of the reduced data rate, the operating system of the computer was able to run unmodified, and was able to support other programs simultaneously. Also, more channels of data could be logged, and through 1977 and 1978 all four S-band channels were recorded.

operating system of the computer was able to run unmodified, and was able to support other programs simultaneously. Also, more channels of data could be logged, and through 1977 and 1978, all four s-band channels were recorded.

Compression

Since much of the volume scanned by the radar does not provide echoes of interest, not all of the possible data locations presented to the computer need to be stored on magnetic tape. To reduce the amount of data stored, data compression is applied to the data before it is written to tape. The method of compression was chosen to allow distinction between areas not represented by data (due to irregular antenna motion, for example) and areas without any echoes of interest. The compression process is also extremely fast, and ensures that compressed data cannot occupy more storage space than uncompressed data.

Position and Time Information

A "header" is placed at the beginning of each compressed ray of data. The header contains the antenna position and the time of day corresponding to the ray. Sufficient information is stored in each header to uniquely identify the following ray, and to accurately position the data in three dimensions. The header also specifies the number of data channels recorded, so that programs can run unchanged using one, two, or four channel data.

Aircraft Positions

The third radar system (X-band) provides non-meteorological data - seeding aircraft positions. This radar is supported by digital hardware which stores the last detected position of each of the eight transponder-equipped seeding aircraft. These positions are read by a computer program every ten seconds and stored on disk. The information is transferred each evening from disk to tape for permanent storage. Aircraft positions are also available to real-time programs.

REAL-TIME

As well as storing the collected data on magnetic tape, the computer system allows programs to examine selected portions of the data as it is being processed (in "real time"). This feature is used to produce contour diagrams of radar reflectivity for seeding aircraft direction. The real-time display system software is shown in figure 1.

Processing data in real time involves the transfer of extremely large (in minicomputer terms) amounts of data in a short time. For example, a plan position indicator display contains over 100,000 data points. It is also important that this data selection and transfer does not interfere with the data collection process. The RSX-11M operating system provides a powerful, versatile set of primitive operations designed specifically for this type of data transfer. The real-time radar data access system utilizes these operations to provide FORTRAN programmers with the ability to use radar data in real-time.

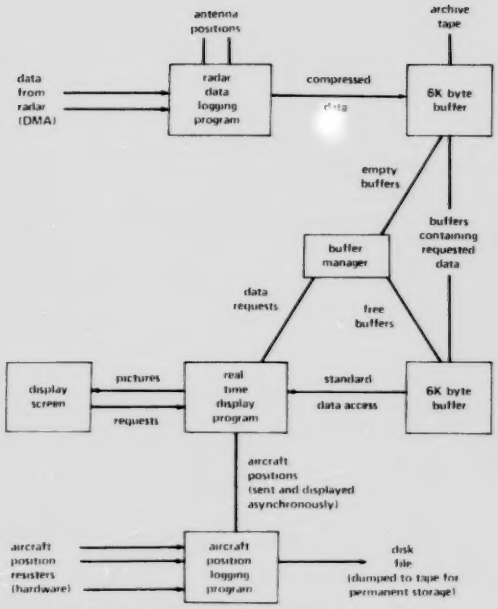

FIGURE 1. Real-time radar data system

Programs written to process real-time data differ from those written to process data from magnetic tape only in the specifics of the real-time application. This allows complex real-time programs to be developed quickly, using the analysis system and tape data, then transferred to the real-time system.

ANALYSIS

Specific support for radar data analysis has been in the form of a library of routines to perform common procedures on the raw data tapes. These routines are written in PDP-11 assembler language to be small and fast. The analysis routines are shown in figure 2.

Data Format

Due to changes in the hardware and software from year to year, the tapes are in slightly different formats. The data extraction library is able to automatically recognize the tape format, and to provide a standard program interface. This allows any program to process data with one, two or four channels and from any year.

Data Conversion

The library also provides reliable, fast conversions from the raw data values on the tapes to more useful units. The calibration information stored on disk is used for this conversion. Restricting these conversions to the routines in this library ensures that compatible data will be produced from all programs using radar tapes.

Coordinate Conversion

Since data is collected in the form of rays, the polar coordinate system is the natural system to use. However, dis-

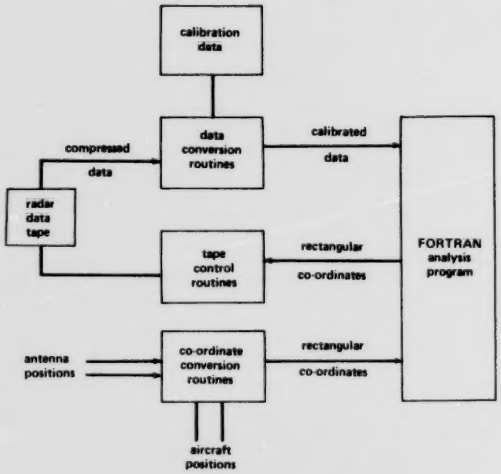

FIGURE 2. Radar analysis software

play and analysis usually require that data positions be specified in rectangular coordinates. A small, fast set of routines is included in the library to facilitate the necessary conversions for radar data, antenna positions, or aircraft positions.

Tape Control

Because of the compression of the data onto the tapes, the structure of the data on the tape is inconvenient for analysis by FORTRAN programs. A set of routines are available to the FORTRAN programmer to control the position of the data tape in terms of time and antenna position. These routines free the programmer from concern about tape format, and provide an efficient method for selecting the desired data from the tape.

HARDWARE

SPECIFICATION

Central Processing Units (CPUs)

The original evaluation of central processors was based on calculated performance measurements using programs required for the software integration process. programs were written in the assembler language of each machine, directly using the hardware, with no operating system overhead considered, and the timings for each machine were based on published speeds, not on actual measurements. For these reasons, it was felt that CPU use of considerably less than 100 percent would actually be the limitation.

At the time of the evaluation, the PDP-11/50 with its high-speed memory capability was one of few minicomputers able to support the processing required for the desired data transfer rate. The 11/50 was chosen from these because of its potential for expansion and multi-user support. The PDP-11/50 processor's speed is partially due to the separate high-speed memory bus, which allows the CPU to run faster than otherwise possible.

The development of the hardware azimuth integration system in 1977 reduced the demand for central processing speed, so the more inexpensive PDP-11/34 system was chosen as the processor for the single-purpose data logging system. Since this processor comes from the same family as the PDP-11/50, all software was immediately operational without rewriting. Also, any software developed on either machine can be run on the other without modification.

Both CPUs are equipped with hardware floating point processors, which increase the speed of non-integer computations, since graphics programs rely heavily on this type of computation. The PDP-11/50 floating point processor is able to perform computations in parallel with integer computations in the CPU, resulting in a further increase in speed.

Memory

The memory of a computer system is used to store programs and data which are currently being used. Several types of memory were installed on the PDP-11/50 system to support specific applications. Because of the speed required for the data collection programs, high speed memory was necessary. This memory was relatively expensive, so just enough was purchased to contain these programs. Memory costs have now decreased to a point where these considerations are no longer as important, and all memory on a system can be fast enough for all but the most time-critical programs. Thus, the current real-time system based on the PDP-11/34 has only one type of memory.

The PDP-11/50 was purchased with 32K bytes of core memory (900 nsec cycle time), and 4K bytes of high speed bipolar memory (300 nsec cycle time) on the separate bug. This memory configuration was adequate for data collection, and limited (non-interactive) displays. Programs were necessarily small, so program development was restricted, and the computer system was available to only one user at a time.

To support multiple concurrent users, as well as larger programs, 128K bytes of low speed MOS memory (1200 nsec cycle time) were added. This memory was later upgraded to 600 nsec cycle time. Finally, 64K bytes of very high speed memory (200 nsec cycle time) were added to permit extensive real-time data processing.

Disks

Disks are used to store programs and data which are not currently in use, or too large to fit in memory. However, access to these programs and data is considerably slower than to those in memory. Large data files and programs under development are typically stored on disk.

Since program development is restricted to the PDP-11/50, the disk system on the PDP-11/34 is fairly

small, consisting of three drives with removable cartridges, each with a capacity of 2.5 million bytes. The removable cartridges allow backups to be kept ready in case the disks on the drives are corrupted. Test versions of the real-time system can also be kept on separate disks.

The software development and analysis demands on the PDP-11/50 system require more extensive disk support. There are three disk drives on this system, each with a capacity of 14 million bytes. Again, removable cartridges provide a backup for reliability and system testing.

Tapes

Magnetic tapes provide the most economical means of long term storage of large amounts of data. All of the radar data collected at AHP are stored on magnetic tapes, accounting for approximately 1500 reels (2400 feet per reel) in five years since 1974.

Two tape drives are required on the data collection system to gather data with no gaps, since several minutes are required to rewind and replace a full tape with a blank tape. Also, the availability of two tape drives on the real-time system permits data collection from two radar systems simultaneously, although with gaps.

Because of the amounts of data involved in radar analysis, two tape drives are often required - one for input of raw data, and one for output of analyzed data. Since tape drives are complex mechanically as well as electronically, their reliability is significantly lower than other components of the computer system (over one third of the computer service calls since 1974 have been due to tape drive problems). Therefore, the PDP-11/50 system has three tape drives so that analysis requiring two tape drives can continue when one drive is down. Also, two separate tape controllers on this system allow two of the three drives to move independently, increasing the overall performance of tape handling programs.

Terminals

All program development and operation is done using on-line, interactive terminals. Several types of terminals are used on the AHP computer systems, each type suited for particular applications.

Typewriter-like terminals which produce copies on paper are slow and noisy, although they produce a permanent record of terminal activity. Paper copies are produced by three of the terminals used on both AHP computer systems. Each system is equipped with an operator's console, which is used for recording system performance information and operator messages, as well as for diagnostic program operation. The third paper copy terminal is located in the telephone survey office in the project's administration building, remote from both computer systems, and is connected via telephone lines. Paper copy was chosen for this terminal since no greater speed is possible, and printouts from the computer systems are otherwise inconvenient to obtain.

The other type of terminal suited to text oriented work consists of a keyboard and a display screen. Because there are no moving parts, output may be as much as thirty times faster than paper copy terminals. Three of these terminals, which are used extensively for program development, text editing, and system control, are available on the analysis system. A highly interactive text editor is available which uses the full capabilities of these terminals.

Since most work done with the radar data involves pictorial displays, terminals capable of graphical interaction are vital to the AHP computer systems. For examples of such applications, see the radar section. Three of the graphics terminals are storage tube terminals, capable of maintaining a picture of arbitrary complexity on the screen, essential in displaying the contour diagrams typical of radar analysis. These terminals are also equipped with a crosshair cursor, which may be positioned manually anywhere on the screen using thumbwheels built into the keyboard. This allows interaction to be entirely graphical.

One of the graphics terminals is actually a complete computer system — the GT40. This is a refreshed display, capable of highly dynamic graphics, although not of the complexity of the storage tubes. Since this terminal has local processing capability, animation and other forms of sophisticated dynamic interaction are feasible.

Finally, to provide remote access to the computer facilities, each system is equipped with a connection to the telephone system, which automatically answers incoming calls and establishes communication with remote computer terminals. This facility is used to provide access to the analysis system from the field site, to monitor the real-time system from Edmonton, and to allow access to radar data for external users.

Output Devices

Although much of the program development and analysis is done using interactive display terminals, permanent paper copies of text and graphics output are often required.

Graphical output of radar data is most often in the form of contour diagrams with appropriate ground references, range rings, and so on. These pictures can be very complex, each consisting of numerous line segments. The most common form of graphical paper output device, the pen plotter, would take a very long time to draw one such picture. The alternative chosen was a matrix printer/plotter, capable of plotting an arbitrarily complex drawing in a few seconds. This device also has the capability of producing shaded drawings, which are valuable for displaying non-continuous data.

Program development requires the routine production of text output, such as program listings and documentation. A 180 character-per-second dot-matrix character printer is used for this purpose, as well as for production of self-adhesive address labels and other special printer forms. This printer is used very heavily, printing approximately 6000 pages per month.

Interfaces

Because of the unique demands of the special purpose hardware involved in the AHP computer systems, several special interfaces have been designed and installed.

Two interfaces pass the digitized signals from the S-band and C-band radar systems to the real-time computer. These interfaces are direct memory access (DMA) devices capable of transferring data into the computer's memory without involving the central processor, thus permitting the very high transfer rates associated with radar data (as high as four eight-bit values every seven microseconds).

Data from the third radar system, the X-band aircraft tracking radar, is processed by a specially designed hardware aircraft tracking system (fully described in the radar section). This system provides the last detected position of each of eight transponder-equipped seeding aircraft. These positions can be read as often as required by the computer system.

Antenna positions (azimuth and elevation) of the two weather radars are provided to the computer via synchro-to-digital converters.

Input Devices

There are two special-purpose input devices on the analysis system — an acoustic digitizing tablet and a modified cassette player. The tablet is used to send digitized coordinates to the computer for the input of graphics such as drawings, charts, or maps. The cassette player reads tapes produced by the distrometer data collection system (see radar section). Both devices are connected to the computer with program controlled interfaces, supported by locally written software (sections on Digitizer Support and Device Drivers). The hardware configuration of the Alberta Hail Project Computer Systems are shown in figures 1 and 2.

RELIABILITY

The computer systems have been maintained by the manufacturer under a standard service contract. The contract supplies on-call service during regular working hours (service is available at other times for an extra charge). Any components which fail are replaced, and devices are upgraded to the latest manufacturing standards. An example of this was a complete replacement of the air system in three of the disk drives. Also included is a monthly maintenance check, including tape and disk drive cleaning and adjusting, and an overall system reliability test.

GENERAL-PURPOSE PROGRAMS

The programs developed by the computing group fall into three major categories: libraries, utilities, and system programs. All programs are extensively documented in unpublished manuals available from the computing group at AHP. This section includes only a brief description of the programs.

LIBRARIES

Libraries are collections of subprograms which can be used as building blocks in larger programs. Collecting these subprograms into libraries makes their documentation, usage and maintenance easier.

TIMESAVER — Low-level Programs

In order to conserve computer memory space, and to provide fast programs, most of the software written by the computing group is coded in assembler language. An extensive library of subprograms has evolved to handle and simplify some of the common operations encountered in assembler language programming. Examples of these operations include message output, extended-precision arithmetic, and command line processing. Each of these subprograms may be accessed in a manner similar to a higher level language statement, making assembler language programming more efficient and comprehensible.

ERRHAND — Error Handling

There are two reasons for supplying a package of programs to process error conditions: simplifying program development, and supplying more understandable error messages to the general computer user. The availability of this error handling subprogram library encourages programmers to provide comprehensible error messages to users.

FODT — Debugging tool for FORTRAN programmers

FODT is a debugging aid which allows the user of RSX-11M FORTRAN VO1C to monitor the operation of his program interactively. FODT was obtained from the Digital Equipment Computer Users' Society (DECUS) and enhanced and extended at AHP. Features include: display of FORTRAN variables, single statement execution, breakpointing, and analysis of program behaviour for optimization.

GRAPHICS — Plotting Support

There are several devices on the AHP computer systems capable of producing graphical output. In order to relieve the applications programmer from the task of understanding each device before writing a program, and to allow users to run any program on any of the available devices, a device-independent graphics library was developed. This set of subprograms supports all of the devices available, and provides scaling and windowing features, as well as the ability to save and restore portions of a picture.

The graphics library was developed as an extremely modular set of subroutines (over 100 modules), so that it could be easily maintained and extended as new devices and requirements became known. Specifically, consideration was given to three-dimensional plotting and conformance with graphics standards currently being developed by the computer industry.

Support for the Versatec printer/plotter was supplied by the manufacturer, but proved to be very expensive to

TABLE 1.
Mainframe Comparisons (1973 Figures)

	Digital Equipment (PDP)			Data General		Interdata		Hewlett Packard	Texas Instruments
Machine	11/40	11/45	11/45 SC (1)	Nova 820	Super-nova SC	Mod 70	Mod 80 (4)	2100S (5)	980A
Mainframe Cost (16KB) ($)	12,500	18,755	24,600	13,000		9,700	15,250	13,000	4975
Type of Memory	Core	Core	Core-Bipolar	Core	MOS	Core	MOS	Core	MOS
Number of General Registers	6	2 x 6 (2)	2 x 6 (2)	4	4	16	16	2	1 (3)
Index Register?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Auto-Increment?	Yes (Reg)	Yes (Reg)	Yes (Reg)	Yes (Mem)	Yes (Mem)	No	No	No	No
Byte Handling?	Yes	Yes	Yes	No	No	Yes	Yes	No	No
Direct Addressing (Words)	28K	28K	28K	4 x 256 (6)	4 x 256 (6)	32K	32K	1K	32K
Average loop:									
Time (μsec)	13.3	9.6	4.2	16.4	11.7	23.3	8.6	41.2	18
Size (Bytes)	10	10	10	26	26	28	28	30	34
Ave. %	56	40	18	69	49	98	36	173	75
Speed/$	6.0	5.6	9.7	4.7		4.4	7.6	1.8	11.2
Compression Loop:									
Time (msec)	3.8	2.6	1.3	2.6	1.6	4.8	1.7	5.3	3.1
Size (Bytes)	60	60	60	64	64	72	72	64	58
Peak %	11	7	4	7	4	14	5	16	9
Speed/$	21.3	20.3	31.1	29.5		21.4	38.8	14.5	64.8

Notes to Table 1:

1. This machine has 20KB of memory: 16KB of core + 4KB of bipolar. The speed per dollar figures are thus about 5% low.
2. Two separate sets of registers are available. Only one set of 6 registers may be used at one time.
3. Special purpose registers are available for indexing, subroutine linkage, and some inter-register operations.
4. The similar Model 85 is available for $22,000. The Model 85 is microprogrammable, and execution times in specific loops may be halved.
5. This machine is microprogrammable. The execution times given could be halved by microprogramming the loops.
6. Four separate "pages" of 256 words each are directly addressable.

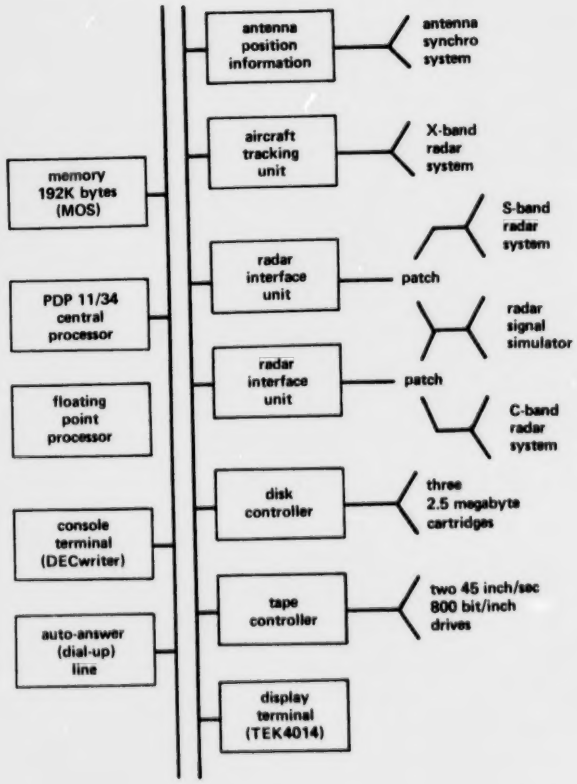

FIGURE 3. Real-time system configuration

operate in terms of computer utilization. A powerful, efficient, and versatile system of programs was developed to support this device. Access to this support is included in the graphics subroutine library.

UTILITIES

In order to make the system more easy to use, a set of utility programs was developed to provide common services to users of the system.

CLG — Comment Log

This utility allows on-line computer users to submit trouble reports, suggestions, or comments to the computing staff. The date and time of the suggestion, and the name of the user are automatically recorded as well.

CNT — Contiguous Space Counter

A common problem on minicomputer systems is a shortage of disk space, especially contiguous space. CNT may be used to determine quickly if sufficient space is available for a program or data file.

DOC — Document Formatter

DOC is an interactive utility which facilitates production of documents in a standard format. Desired formats are established as templates, and DOC guides the user through the steps required to fill in the appropriate information. This ensures that sections are not inadvertantly omitted, and provides a uniform appearance for a set of documents.

DTZ — Digitizer Support

DTZ provides general purpose support for the acoustic digitizing tablet. Coordinates specified by the position of the pen on the tablet are stored in a data file which may be used as input to other programs. Files produced by DTZ may be plotted or examined at a terminal using another utility, DTV. Specific applications using the digitizer may read data directly using the device driver described in the section on Device Drivers.

EVF — Event Flag Manipulator

Programs in an RSX-11M system communicate with each other via a set of on/off signals, called "event flags." EVF allows a user to interactively display and control these flags.

FLY — Multi-column Formatter

To conserve paper and printer time, a program was developed to produce multiple columns of output on each page. This program is called automatically when output is printed, and also may be used explicitly to produce any specific multicolumn format.

HELP — On-line Help

Typing "HELP" at any AHP computer terminal initiates a program which will display a brief description of common error messages or commands for many of the utility programs. This program also records any unsatisfied requests for help along with the user's name, so that the computing staff can increase the help available, or contact the user directly. This form of on-line documentation may be kept up to date easily, can be tailored to the needs of a particular group of users, and reduces the need for multiple copies of the expensive system reference manuals.

LOG — Personal Log Book

Each user on the system may have an individual on-line log, and use the LOG utility to add entries to it. The date and time the entry was made is automatically inserted in the log.

This utility is used extensively by the radar staff during the summer to record radar performance measurements and comments regarding radar operation. This log is saved and examined periodically by supervisory staff to isolate recurring problems.

MAIL — Message Utility

MAIL allows users to send messages to other users, without requiring that both users be on-line simultane-

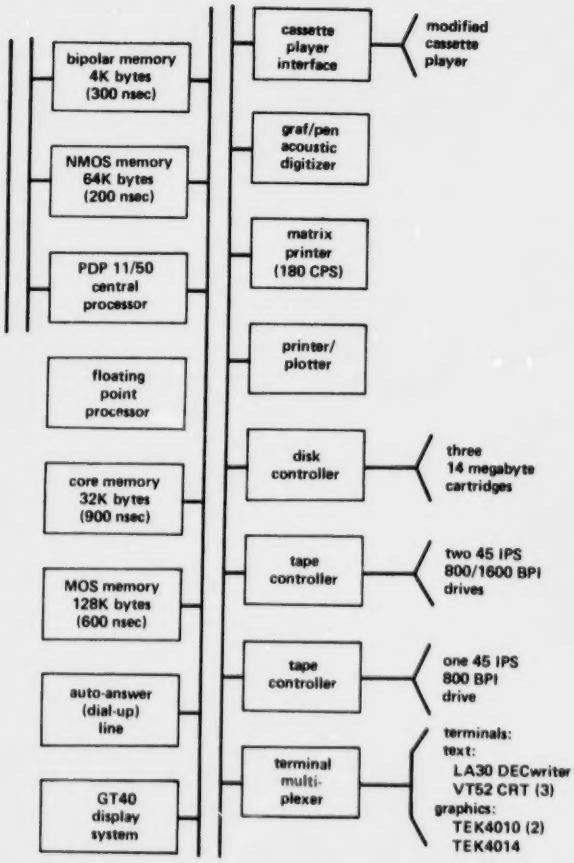

FIGURE 4. Analysis system configuration

ously. Each user is notified of any messages whenever he signs on to the system.

Mailing lists of users with common interests may be established, and copies of a message sent to everyone on the list with a single command. A reply is automatically requested after a message is read, and the sender is notified of the date and time the message was read, along with the reply from the receiver.

PRT — Printer Control Program

Output to the printer may be sent by many separate users, often at terminals located in different offices. To keep each output intact, a queue of files to be printed is maintained, and the files are printed from this queue sequentially. The PRT utility program controls the queue of files, allowing files to be added or deleted, to be moved to the front of the queue, or to be reprinted if there are problems with the printer.

RAT — Tape Drive Control

RAT is an interactive utility used to control the tape drives from a remote terminal. Tapes may be examined or moved to any position, forward or backward. Tape drive characteristics may be set or examined. This utility reduces the need for users to go to the computer room to control tape operations.

SND — On-line Message Utility

SND allows a message to be sent from one terminal to another. With SND, a message of any length can be sent from the issuing terminal to any one or all of the other available terminals.

SRT — Sort Program

SRT is a disk file sorting program based on multiple applications of an efficient sorting algorithm (QUICKSORT), followed by a series of merges. The technique chosen will sort files as large as the available disk space. Sort keys may be chosen as a combination of as many as five fields of arbitrary length.

SYSTEM

RSX-11M is designed as a real-time system, and includes many of the general-purpose tools necessary for this type of application. Wherever possible, additional features added to the system were made compatible with the RSX design philosophy to provide a consistent appearance to programmers and users.

Device Drivers

Some of the special purpose hardware used on the AHP computer systems is not supported by RSX-11M as distributed by the manufacturer. To permit access to these devices without the necessity of special-purpose programs, and to protect on-line users from unexpected system failures while these devices are being used, software was developed to support these devices in a manner compatible with the standard RSX-11M devices. This makes development and testing of programs which use the devices easier, and permits other users to continue to use the system without interruption.

(1) **RD**: The radar interfaces (S-band and C-band) are high-speed, direct memory access devices. In order to collect data from the radars, the software controlling the interfaces must respond quickly, and with very low overhead. This support is achieved using a device driver written at AHP which controls both radar interfaces. This driver allows programs to obtain data at a very high rate, with no danger of interfering with other system activities.

Most features of the interface hardware are available to programs using the driver, so special-purpose programming is no longer necessary. Sufficient flexibility is available so that diagnostic programs may be written using the driver software, and tests may be run on one interface while the other is collecting data. Support of both radar data interfaces within one driver reduces the memory requirements of the data collection system.

(2) **GP**: Two other devices are peculiar to the AHP computer system — an acoustic digitizing tablet, and a modified cassette player (see the radar section for a full description of the cassette system). These two devices are

supported by a common driver, and are available to programmers in a manner similar to other RSX devices.

(3) **MC**: The Monitor Command (MC) driver is an example of the computing group's effort to provide programmers with uniform extensions of the operating system. The MC device appears to programs the same as other devices on the system, but lines written to it are passed to the system command interpreter. This allows programs written by any user to use the full capability of the system in a familiar manner.

(4) **GT40**: The GT40 display system is connected to the PDP-11/50 via an interprocessor link called a UNIBUS window. This device allows data transfer between these two computers at a speed comparable to that of main memory. The device driver fully supports this complex device, allowing programs to transfer data at this speed.

GT40 Terminal Support

The GT40 terminal includes a small PDP-11 processor and a local memory. This machine has been programmed to provide user-oriented terminal support features such as a time-of-day clock display, scrolling and buffering of text, and automatic entry of commonly used text strings. Graphic displays are also supported by this software.

System Resource Accounting

The resources of the PDP-11/50 analysis system are nearly exhausted by the demands of data analysis and program development. A set of accounting programs was developed to record resource usage data, which may be used to identify bottlenecks in system performance, to issue warnings to careless users of depleted resources, and to provide an indication of the resources consumed by individual users. Monthly reports are prepared to indicate the fraction of each resource consumed by each user.

(1) **Disk space**: Disk space is one of the more limited resources (typically only 5% of the total space is unused), so warning messages are issued if a user occupies more than a pre-allocated amount of space. Records of disk space use are accumulated, and reported at the end of each month.

(2) **Paper**: Consumption of paper on both the printer and the printer/plotter is recorded per user. This information is also used for scheduling routine maintenance on these devices.

(3) **Devices**: Tape drive and terminal time for each user are recorded and reported monthly.

CHG — Privilege Control

Control and monitoring of the computer system is accomplished using a terminal, however there are insufficient terminals available to allocate one entirely for this purpose. The CHG utility allows control of system to be assumed from any terminal.

DVQ — System Monitor

To achieve the maximum efficiency from a computer system, the load on various devices and programs must be optimized. A program to dynamically display these loads was developed, and is used frequently.

STF — Command Stuffer

Managing the operation of a multi-user system includes handling uncooperative or naive users. The STF utility allows a system manager to send commands to a user's terminal to terminate programs, issue complex commands, or sign off the system. This facility is especially important for terminals connected via the dial-up line and the telephone system.

OPERATIONS

FIELD OPERATIONS

While data collection programs were being developed, experienced computer oriented personnel were required to support their operation. By the summer of 1978, these programs were sufficiently reliable to be included as part of the routine operations of the radar system. Program development and data analysis tasks have not been performed on the computer at the field site since 1977.

Wherever possible, man-computer dialogues were established to perform the actions required for computer operations. These dialogues are initiated by simple commands, and the computer requests further information from the operator as necessary. This procedure ensures that all necessary actions are carried out, yet provides flexibility in actual operations.

Such dialogues were established to start and stop radar data logging, to initiate the aircraft tracking system, to activate the real-time data display program, and to perform the daily copy of files from disk to tape. Each of these dialogues requests the initials of the operator, and automatically inserts a timed entry into the operations log. Potentially conflicting activities (such as calibrating a radar which is collecting data) are detected, and the operator is informed of the error.

Each evening in 1978, a tape was made containing the operations log, radar calibration data, and aircraft position data. This tape, and the radar data tapes collected during the day were shipped by bus to the analysis facility in Edmonton. The data rate represented by this method of data transfer is the equivalent of twenty-four hour operation of the fastest communication lines available. In 1978, 648 tapes were shipped on 91 days, resulting in an average data rate of over 100,000 bits per second.

Completely routine activities which do not require operator intervention are scheduled and initiated automatically by the computer. For example, each night at midnight, the system automatically copies to a backup disk all data files which have not yet been copied to tape and sent to Edmonton. These files remain on the backup disk until a copy has been transferred to tape, and the quality of the data verified.

RESEARCH/ANALYSIS OPERATIONS

The PDP-11/50 system supports several diverse analysis activities, each with specific demands upon computing resources. These activities may be identified as the following types: routine data analysis, interactive data analysis, radar data based research, program development, system development, and system maintenance. The demands of each of these activities are described below, followed by the resource allocation system established to resolve the inevitable conflicts.

Demands

Each type of analysis activity makes a unique set of demands on the system resources, including human operators, software, and hardware.

Routine Analysis

Routine data analysis is based on well-defined operations, and well-tested programs, thus very little human intervention is required. This type of program typically runs unattended for long periods of time. Tape copying to provide a secure and reliable archive is an example of this type of processing. Each data tape is copied to provide a tape to be used for analysis, and the original tape is sent, unchanged, to the University of Alberta Department of Computing Services for archival storage. The copying process requires very little CPU time, but occupies two tape drives for approximately twenty minutes per tape, and demands the attention of an operator for mounting, dismounting, labelling and shipping tapes. Another example of routine processing is the production of CAPPI tapes, fully described in the radar section.

This type of processing is run at a low priority, whenever sufficient resources (usually tape drives) are not being used for the other activities described below. Urgent demands for analysis of specific data are met by operating the computer on weekends or during evenings, so that the system is available during regular working hours for those activities involving more people.

Interactive Analysis

This analysis is similar to the routine analysis described above, but requires the continuous attention of a trained analyst, with a computer terminal. The analyst directs the processing using the terminal, and therefore requires some training in both meteorology and computer operation, although careful interactive program design can somewhat alleviate the need for the latter. Examples of this analysis include data extraction, storm identification, and cloud height calculations.

Radar Data Based Research

Computer-based radar research usually requires close cooperation between the scientist involved and a computer programmer familiar with the radar data and the computer system. Hypotheses are formalized into programs, and results are produced from the data tapes. Further analysis of these results leads to respecification and refinement of the computer program, and more data processing. This evolving analysis requires computer support for the intensive activity required to produce the intermediate results.

Program Development

Program development refers to the writing, debugging, and documenting of the programs used in the various types of analysis. The tools for this work such as text editors, printer controllers, and disk space managers, are equally applicable to programs or documentation. A text formatting system allows on-line maintenance of the documents, so that they are easily available and up to date. Except for test runs, program development requires simple computer terminals, access to the line printer, and disk storage for programs and text. The multi-user nature of the RSX-11M system allows several programmers to proceed with program development simultaneously.

System Development

The group of people interacting with the computer system include scientists, programmers, and technicians. The

TABLE 2
Processor Comparisons (1973 Figures)

Year	S-band Number of tapes	S-band Number of days	S-band Time (min.)	C-band Number of tapes	C-band Number of days	C-band Time (min.)
1974	0	0	0	53	17	5792
1975	151	42	16418	6	3	794
1976	179	36	15128	0	0	0
1977	438	83	41425	10	9	1096
1978	534	91	51311	114	70	45552
TOTAL	1302	252	124282	183	99	53234

goal of system development has been to make the computer easier to use for all of these people. For those unfamiliar with computers, on-line help is available to provide answers to questions at a terminal. Programmers are assisted by extensions to the system which provide additional functionality.

System Maintenance

As well as being easy to use, a computer system must be reliable and available. Reliability is provided by error-logging programs which record hardware errors, so that a failing device may be identified. On-line diagnostic programs test devices without interfering with other system activity. All data and programs stored on disk are copied to magnetic tapes each day, so that a hardware failure will not result in an extensive loss.

Scheduling

A scheduling system has been developed to coordinate the use of the analysis computer system. Since the majority of analysis is based on interactive graphical displays of radar data, the computer resources most often required are a graphics terminal and a tape drive. The reservation of this combination of hardware for four hour blocks has been defined as the basic unit of computer resource, the Available Machine Unit, or AMU.

A special case is made for the analysis requiring two tape drives simultaneously, such as data extraction, or tape copying. These activities require two concurrent AMUs, and this unit is identified for scheduling purposes as a double AMU.

There are three tape drives and three graphics terminals on the analysis system, so there are six AMUs available during regular hours each day — three in the morning and three in the afternoon. AMUs may also be allocated during the evenings and on weekends, so that a total of 63 AMUs are available each week, 30 during regular working hours.

The changing demands of ongoing research preclude a fixed schedule of AMU allocation, so requirements and allocations are re-assessed each week. AMU request forms are completed by computer users, and a senior administrator resolves any conflicts based on knowledge of the research priorities represented by the request forms. The final allocation is posted, so that users can schedule research activities for the week, based on the available computer time.

Any remaining computer time is available to users on a first-come, first-serve basis, coordinated through the computer operator. The text terminals and other devices are also scheduled this way.

DOCUMENTATION OF COMPUTER SOFTWARE FOR PROCESSING DIGITAL WEATHER RADAR DATA AT THE ALBERTA RESEARCH COUNCIL

J. Ramsden
R. Drobig
B. Wm. Folliott

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DOCUMENTATION OF COMPUTER SOFTWARE FOR PROCESSING DIGITAL WEATHER-RADAR DATA AT THE ALBERTA RESEARCH COUNCIL

J. Ramsden, R. Drobig, B. Wm. Folliott

INTRODUCTION

Digital data from the Alberta Research Council's S-band radar at Penhold played an important part in both the operational and research programs of the first five years of the Alberta Hail Project. The effective use of this data depended upon the development of computer software for manipulating, displaying, and analyzing the digital data. Development of this software was undertaken by the Radar Group of the Atmospheric Sciences Division of the Alberta Research Council.

The present report has three purposes. First, it provides preliminary documentation of all radar-related computer software developed by the Radar Group during the first five years of the Alberta Hail Project. Second, it outlines certain principles of software documentation developed by the Radar Group, and currently being used as a basis for complete documentation of all the programs for which preliminary documentation is given here. Third, it gives an example of a complete program document based on these principles.

The text of the report contains an introduction to the principles of software documentation developed by the radar group, and describes the documentation scheme developed in accordance with these principles. An abbreviated documentation of the programs is placed in Appendix 1. An example of a fully documented program is given in Appendix 2.

PRINCIPLES OF SOFTWARE DOCUMENTATION

Expenditure of resources to develop computer software without adequate documentation is a poor investment. Full documentation permits the software to be used to its full potential, updated as required by changes in the user's requirements or changes in the computer system, corrected when errors are detected, and implemented on computer systems other than the original one. Modification or adaptation of undocumented software is at worst impossible, and at best very difficult and therefore expensive.

Different kinds of software documentation are required for different purposes, ranging from simple non-technical descriptions for progress reports intended to be read by non-scientists, to complete descriptions including much technical information for use by computer programmers. These purposes may be listed in order of increasing technical content as follows:

(1) To report progress in non-technical terms to people such as managers, politicians, the public, and scientists in other disciplines.
(2) To report significant progress to scientists familiar with the subject matter.
(3) To enable computer operators to run the program(s).
(4) To enable system analysts to install the program(s) on another computer system.
(5) To enable programmers to maintain and update the program(s).

The amount of detail included in a software description is determined by the purpose of the description, which is related to the kind of reader expected, as shown in table 1. The descriptions for various purposes can be arranged in order of increasing detail as follows:

On the highest level (level 1) the description is short, non-technical, and should be understandable by anyone. It is not so much a description of the software itself as it is a statement, in very general terms, of the data-processing capability that the software provides.

At the next level (level 2) is a complete definition of the task performed by the software in non-computer-related terms. This description includes such information as the inputs required, the outputs produced, restrictions, methods, and options. Logical flowcharts may be included at this level. This is the kind of description the person requesting the software development might present as a set of "design requirements". It is also the kind of description that would be meaningful to a scientist familiar with the subject matter but not interested in computing details.

The description on the next level (level 3) contains all the information required to operate the program(s). This would consist of a complete description of all inputs and outputs, including options and control parameters, with formats. Thus at this level the interfaces between the program and the input and output information are precisely defined. A description of the program at this level would enable a user/operator to set up the required data files in the proper formats, and run the program selecting appropriate options.

At the next level (level 4) the interfaces between the program and the computer system are precisely defined. This includes the memory required, operating-system features, input/output device characteristics, and supporting software. This level of detail enables a system analyst to determine the feasibility of running the program on another computer system, and to plan and execute the details of the installation.

The description at level 5 deals with the internal features of the program(s), including the logical structure of the program(s), common blocks, data structures, and the functions and interrelationships of software modules

TABLE 1
Levels of Software Documentation

Level	Name	Whom for	Purpose	Contents
1	Identification; non-technical description	Managers; politicans; scientists in other fields.	To report progress	Statement of data-processing capability and implications
2	Task definition	Programmer/ analyst scientists in same field	Request software development Report state of computer-processing	Description of task in technical but non-computer language, inputs, outputs, restrictions, capabilities, methods, options, examples.
3	Operation	Computer operator	Permit operation of program	Precise inputs, outputs, formats, parameters, defines program/data interfaces.
4	Computer system	System analyst	Permit installation of program	Defines program/computer interface: memory, input-output devices; software.
5	Internal features	Senior programmer	Design of program modifications	Internal structure; common blocks; data structures; description of modules.
6	Source code	Programmer	Modification of program	Source code with comments.

within the program(s). Flowcharts are an essential part of the description at this level. This level includes precise definitions of the interfaces between modules, but does not include internal features of modules.

The information at this and lower levels is required by a programmer modifying the program for any reason. If a program is never to be modified, no description below the previous level is necessary. However, almost all programs are modified for one reason or another (updating, enhancement, error correction), and even for small programs it is cheaper to change a program than to rewrite it. So a description at this level should be prepared for every program.

The level 6 description contains information pertaining to the internal operation of individual modules. While flow diagrams could be included for complex modules, the documentation at this level is basically the source code itself, with whatever comments the programmer sees fit to include therein.

If several interrelated programs form a package, the package itself should be described on levels 1 to 4 inclusive, while each individual program in the package should be fully described using all levels.

In view of the variety of purposes for which documentation is required, it is desirable for the documentation itself to be structured to permit easy extraction from the total documentation of those portions required for a particular purpose. Moreover, the entire documentation for a program may not be written all at once. There should be a plan for orderly development of the documentation, beginning with the most essential parts and proceeding step by step until the documentation is complete. These two principles led to the development of a software-documentation scheme.

Software-Documentation Scheme

A scheme for software documentation was developed with the above principles in mind. This scheme is outlined in table 2. The sections numbered 1 through 6 represent increasing amounts of technical detail and correspond to the six levels of documentation described above; they also represent a reasonable sequence for documenting. If each numbered section constitutes one chapter of the final document, then the document can be compiled chapter by chapter as each section (level) of the documentation is completed. It is then also convenient to extract the documentation down to the level appropriate for a particular purpose.

When a program is installed on a particular computer system, many of the details of program installation and operation are peculiar to that system. In the documentation scheme, system-specific information is kept separate and placed in two additional chapters: Chapter 7 describes system-specific installation procedures, and Chapter 8 describes system-specific operating procedures. This makes it easy for readers at other institutions to recognize those parts of the documentation that are system-specific, and simplifies the task of adapting the documentation to describe the software as implemented on their computer system.

TABLE 2
Computer Software Documentation — Outline

Introduction

1 Identification
- Name
- Title
- Abstract
- Author
- Originating Organization
- Date written
- Version
- Source Language
- Related Programs

2 Function
- Narrative Description
- Method
- Limits
- Data Inputs
- Mode of Operation
- Options
- Printed Outputs
- Other Outputs
- Flowchart
- Examples

3 Operation
- Inputs
- Outputs
- Normal Operation
- Error Messages and Error Recovery

4 Computer System Requirements
- Peripheral Equipment
- Support software
  - System Routines
  - Library Routines
- Total Program Size
- File Specifications
- Original System

5 Internal Features
- Program Structure
- Data Structures
- Common Blocks
- Module "_____"
  - Function
  - Calling Sequence
  - Inputs
- Module "_____"
- etc.

6 Source Listings

7 Installation Instructions
- Devices
- Location of Supporting Software
- Operating-System Commands
- Indirect Command Files
- Overlay-Structure description
- Task-file location

8 Operating Instructions
- Set-up Procedures
  - Location of Input files
- Running Procedures
  - Operating System Commands
  - Indirect Command files
- Take-down procedures
- Labelling and Disposition of Output
- Name of Program Maintainer

SUMMARY AND CONCLUSIONS

Full documentation of computer software is sound protection for the original investment in the development of the software itself. Fully documented software can be used to its full potential even in the absence of the original programmer, can be upgraded and updated as required, and can be implemented on computer systems other than that for which it was originally developed.

Documentation is used for many purposes, each requiring a different level of technical detail. Documentation may be developed in sections over a considerable period of time. Both of these observations point to a need for the documentation to be structured so that (a) documentation down to the appropriate level can be easily extracted for a particular purpose, and (b) the structure of the documentation acts as a guide for orderly step by step development of the documentation. A scheme for software documentation has been developed that satisfies both of these requirements.

ACKNOWLEDGMENTS

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COMPUTER SOFTWARE DOCUMENTATION

APPENDIX 1

PROGRAM ABSTRACTS

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BASIC RADAR-DATA ACCESS AND EXTRACTION

Name: BIRDD

Title: Basic Interactive RaDar Display

Abstract: This is a general-purpose program providing access to the stored digital radar data (both S-band and C-band). First, the program permits rapid retrieval and display of the data on a CRT screen in the form of contoured maps of either radar reflectivity or rainfall rate. Optional range rings, towns, and movable "ground reference" markers facilitate interpretation of the display. Paper copies of any display can be easily obtained.

Second, the program permits the operator to extract selected noise-free data from a specified geographic region, for subsequent computer processing. The region from which data are to be extracted is "drawn" by the user directly on the CRT display using a pointing device connected to the computer.

The program is designed to be easily usable by persons without skill or experience in dealing with computers. The user controls the program simply by pointing, with the pointing device, to words displayed on the screen.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1976-03-01

Version: 1978-09-08

Source Language: PDP-11 FORTRAN

Related Programs: TAPSUM TAPDAT TAPCON

Name: FOUR

Title: Four-Channel Radar-Data Extraction

Abstract: FOUR allows one to obtain listings of various radar quantities from the logged radar tapes. The data are also saved in a disk file which can be used for further analysis by such programs as FIVE.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1977-06-01

Version: 1978-07-10

Source Language: PDP-11 FORTRAN

Related Programs: FIVE

Name: TAPCON

Title: Contour extracted radar data on tape

Abstract: This interactive program contours extracted radar data stored on the tape.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1976-09-01

Version: 1977-09-01

Source Language: PDP-11 FORTRAN

Related Programs: TAPDAT TAPSUM BIRDD

Name: TAPDAT

Title: An interactive program to produce printer listings of data extracted by BIRDD

Abstract: TAPDAT produces listings, suitably formatted and titled, of radar data that has been extracted to tape by BIRDD. The user specifies which file and which windows in that file are to be printed.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1976-09-01

Version: 1977-09-01

Source Language: PDP-11-FORTRAN

Related Programs: BIRDD TAPSUM TAPCON

Name: TAPSUM

Title: Summarize contents of extracted data tape

Abstract: This program summarizes the contents of an extracted data tape.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1976-09-01

Version: 1977-09-01

Source Language: PDP-11 FORTRAN

Related Programs: BIRDD TAPCON TAPDAT

Name: FLGCNT

Title: Radar Data tape error flag count program

Abstract: This program counts the number of error flags on radar-data tapes recorded in 1977 and later. The program outputs the time of each flag, the totals and the number of rays of radar data processed.

Author: Stephen K. Leung

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1977-11-01

Version: 1977-11-01

Source Language: PDP-11 FORTRAN

Related Programs:

CONSTANT-ALTITUDE MAPS

Name: CAPCON

Title: Contour CAPPIs

Abstract: An interactive program to contour extracted CAPPIs with optional paper copies. The user is able to specify a CAPPI by time o by relative number to the current CAPPI. A series of CAPPIs can also be specified.

Author: B. Wm. Folliott

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-07-01

Version: 1978-07-01

Source Language: PDP-11 FORTRAN

Related Programs: X Z Q M S HYDRO

Name: X

Title: CAPPI extraction program

Abstract: This program extracts the CAPPI and stores the extracted data on a magnetic tape. At the same time the data is passed on to the programs Z and Q.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: X Z Q M S HYDRO

Name: Z

Title: Extracts data for Constant Altitude PPIs

Abstract: This program creates constant altitude PPIs by extracting the necessary data from the raw data tapes and stores the CAPPIs on magnetic tape for future study. The program also makes the extracted data available to other programs which process the data in parallel with the extraction process.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: X Z Q M S HYDRO

Name: DUMP

Title: Dump CAPPI

Abstract: This program dumps one CAPPI to the line printer for inspection. In this way the correctness of the CAPPI can be checked.

Author: B. Wm. Folliott

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written:

Version:

Source Language: PDP-11 FORTRAN

Related Programs:

PRECIPITATION MEASUREMENTS

Name: Q

Title: Calculates accumulated rainfall

Abstract: Q uses the two latest reflectivity CAPPIs to compute rainfall amounts and update the accumulated rainfall CAPPI. The average rainfall rate for each subbasin is also computed and stored in a file, then is later used to produce a summary table.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: X Z Q M S HYDRO

Name: M

Title: Produces printer map of accumulated rainfall

Abstract: M produces an 8 mile/inch printer map of the accumulated rainfall CAPPI for the Alberta Hail Project area.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: X Z M Q S HYDRO

Name: S

Title: Produce Rainfall Summary Table

Abstract: S produces a formatted rainfall amount summary table by river basin and subbasin, using the matrix of subbasin rainfall rates compiled by Q. The rainfall is tabulated on an hourly basis.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: X Z S Q M HYDRO

PRINTED REFLECTIVITY MAPS

Name: DBZMAP

Title: 16 mi/in printer map of radar reflectivity

Abstract: DBZMAP uses the latest CAPPI to produce a printer map of reflectivity.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-04-01

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: SPLMAP MAXMAP

Name: MAXMAP

Title: Maximum Reflectivity Map

Abstract: MAXMAP updates the maximum reflectivity map using the printer map of the latest reflectivity CAPPI.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: DBZMAP MAXMAP

Name: SPLMAP

Title: Print Map

Abstract: SPLMAP combines the latest CAPPI printer map with an overlay and prints the map.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: DBZMAP MAXMAP

RADAR/GROUND COMPARISONS

Name: BASINS

Title: Basic rainfall accumulator

Abstract: This program uses the archived radar data to average the amount of rain that fell in a particular basin over a certain period of time.

Author: J. Ramsden

Originating Organization
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-04-01

Version:

Source Language: PDP-11 FORTRAN

Related Programs: GAUGES

Name: COORD

Title: Coordinate conversion

Abstract: This program converts legal land descriptions into radar coordinates.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1977-09-01

Version:

Source Language: PDP-11 FORTRAN

Related Programs:

Name: GAUGES

Title: Point Rainfall Accumulator

Abstract: This program uses the archived radar data to calculate the amount of rainfall at a specified location during a specified time interval.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-04-01

Version:

Source Language: PDP-11 FORTRAN

Related Programs: BASINS

Name: RAINPLOT

Title: Plot gauge-derived rainfall and radar-derived rainfall

Abstract: Plots rainfall rate vs time or accumulated rainfall vs time for either or both of gauge-derived and radar-derived rainfall estimates.

Author: J. Ramsden

Originating Organization
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-04-01

Version:

Source Language: PDP-11 FORTRAN

Related Programs: BASINS GAUGES

DUAL-WAVELENGTH AND POLARIZATION STUDIES

Name: FIVE

Title: Dual-Wavelength Studies

Abstract: FIVE is a program used in dual-wavelength studies of S-band and C-band data that are close in time and space. This data will have been previously extracted by FOUR. FIVE performs two operations: first, one set of data is interpolated according to the azimuth of the second set of data; second, the interpolated data are subtracted from the second set of data. The differences are printed in the form of a map.

Author: B. Wm. Folliott

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-07-01

Version: 1978-07-01

Source Language: PDP-11 FORTRAN

Related Programs: FOUR TAB TABLE

Name: GRAB

Title: GRAph of Bin positions

Abstract: The program produces a graph showing the positions of specified radar bins in a range-height coordinate system.

Author: Reinhard Drobig

Originating Organization
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-09-01

Version: 1978-09-01

Source Language: PDP-11 FORTRAN

Related Programs: FIVE TAB TABLE

Name: TAB

Title: Tabulate coordinate data by time.

Abstract: TAB generates the input files for the program TABLE. For each second of logged radar data in a specified time period, the average elevation is evaluated and printed out along with the azimuth and time. This is done for corresponding sets of S-band and C-band data.

Author: B. Wm. Folliott

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: TABLE FIVE GRAB

Name: TABLE

Title: Correlate S- and C-band coordinate data

Abstract: TABLE produces a table of coordinate data which shows how the S-band and C-band radars, when slaved together, are rotating with respect to each other. Data produced by TAB for the S-and C-band radars are matched in time and the difference in the elevations is calculated. This is printed in a table together with the azimuth of the two radars. The task of matching data from the two radars in time and space becomes much easier using this table.

Author: B. Wm. Folliott

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978

Version: 1978

Source Language: PDP-11 FORTRAN

Related Programs: TAB FIVE GRAB

Name: ANTPOS

Title: Antenna positions display program

Abstract: This interactive program prints antenna pointing directions on a terminal and calculates the differences between the S-Band and C-Band antenna directions. The difference calculation is repeated 50 times to estimate slaving errors.

Author: Stephen K. Leung

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-03-01

Version: 1978-03-01

Source Language: PDP-11 FORTRAN

Related Programs:

Name: BITCHK

Title: Aircraft-tracking unit maintenance bit-check program

Abstract: This interactive program tests for stuck bits in the antenna synchro and aircraft position data lines. This ensures that the data recorded by the computer are accurate.

Author: Stephen K. Leung

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-03-01

Version: 1978-03-01

Source Language: PDP-11 FORTRAN

Related Programs:

AIRCRAFT-TRACK DATA PROCESSING

Name: AIRPLOT

Title: Plot aircraft tracks

Abstract: This program plots the positions of research or cloud-seeding aircraft for a specified day.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-09-01

Version: 1978-09-01

Source Language: PDP-11 FORTRAN

Related Programs: AIRPRNT AIRSCAL

Name: AIRPRNT

Title: Print aircraft positions

Abstract: This program prints out all aircraft positions sorted by aircraft. The position of the aircraft is given with respect to Edmonton, Calgary, and Penhold. The range is shown in kilometres, miles, and nautical miles.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-09-01

Version: 1978-09-01

Source Language: PDP-11 FORTRAN

Related Programs: AIRPLOT AIRSCAL

Name: AIRSCAL

Title: Plot aircraft tracks to scale

Abstract: This program plots selected aircraft tracks for a specified time period at a specified scale. Special symbols are also plotted to indicate the beginning and ending of the track.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-09-01

Version: 1978-09-01

Source Language: PDP-11 FORTRAN

Related Programs: AIRPLOT AIRPRNT

Name: ACPOS

Title: Aircraft position display program

Abstract: This interactive program prints aircraft positions on the terminal. As aircraft numbers are entered their positions in azimuth and range (in miles) are printed.

Author: Stephen K. Leung

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-03-01

Version: 1978-03-01

Source Language: PDP-11 FORTRAN

Related Programs:

RADAR OPERATIONS

Name: CAPLOT

Title: CAlibration file PLOTting program

Abstract: The purpose of this program is to plot the radar calibration files so that the best calibration for the day can be determined.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1976-11-09

Version: 1978-06-01

Source Language: PDP-11 FORTRAN

Related Programs: TRPT SUNPOS

Name: SUNPOS

Title: Sun position calculation program

Abstract: This program calculates the position of the sun in azimuth and elevation relative to a given location in the northern hemisphere. It is used to calibrate the radar antenna position indicators. The program calculates the sun position in half-minute intervals for a specified time interval.

Author: Stephen K. Leung

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1977-10-01

Version: 1977-10-01

Source Language: PDP-11 FORTRAN

Related Programs: CAPLOT TRPT

Name: TRPT

Title: Terminal plotting program

Abstract: This program takes a data file created by CAPLOT (calibration plot) and prints a graph on the terminal. It is used to produce a plot of a calibration file in the absence of the printer/plotter as in Penhold. Provision is made to automatically distinguish between receiver calibrations as well as printing of port numbers, time and date of calibrations.

Author: Stephen K. Leung

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-03-01

Version: 1978-03-01

Source Language: PDP-11 FORTRAN

Related Programs: CAPLOT SUNPOS

DISTROMETER-DATA PROCESSING

Name: DSTTPREAD

Title: DiSTrometer TaPe READ

Abstract: This program transfers data from a distrometer cassette tape to computer tape.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1977-12-01

Version: 1977-12-01

Source Language: PDP-11 FORTRAN

Related Programs: QUERY FANMAIN CHEAT LOOK PEEK

Name: FANMAIN

Title: Final ANalysis MAIN program

Abstract: The output produced by QUERY and DSTTPREAD is combined and reformatted by this program. FANMAIN also removes any incorrect data and produces a quality analysis of the input data. A drop size distribution graph of the error free output data is also produced.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-01-01

Version: 1978-01-01

Source Language: PDP-11 FORTRAN

Related Programs: QUERY DSTTPREAD CHEAT LOOK PEEK

Name: QUERY

Title: Query the user for information about each distrometer sample.

Abstract: QUERY is a program which prompts the user for information about a distrometer sample and then after having checked the information, stores it on magnetic tape in a computer readable format.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-01-01

Version: 1978-01-01

Source Language: PDP-11 FORTRAN

Related Programs: DSTTPREAD FANMAIN CHEAT LOOK PEEK

Name: CHEAT

Title: Find and correct hardware problems

Abstract: This program analyses the output from DSTTPREAD for stuck bits and can be used in some cases to erase or set specified bits to make the data acceptable to FANMAIN.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-02-01

Version: 1978-02-01

Source Language: PDP-11 FORTRAN

Related Programs: QUERY DSTTPREAD FANMAIN LOOK PEEK

Name: LOOK

Title: Look at the output from FANMAIN

Abstract: This program allows the user to inspect the output of the FANMAIN program.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-05-01

Version: 1978-05-01

Source Language: PDP-11 FORTRAN

Related Programs: QUERY DSTTPREAD FANMAIN CHEAT PEEK

Name: PEEK

Title: To check the output from DSTTPREAD

Abstract: This program prints specified portions of the DSTTPREAD output tape allowing the user to inspect the data before processing by FANMAIN.

Author: Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-02-01

Version: 1978-02-01

Source Language: PDP-11 FORTRAN

Related Programs: QUERY DSTTPREAD FANMAIN CHEAT LOOK

REAL TIME DATA PROCESSING

Name: FLOW

Title: Plots contoured maps of rainfall rates

Abstract: This program plots the instantaneous rainfall rates over selected river basins in the project area. The data is obtained in real time and the resulting map is contoured in 5 MM/HR increments.

Author: J. Ramsden

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written:

Version:

Source Language: PDP-11 FORTRAN

Related Programs:

Name: HYDRO

Title: Real-time C-band rainfall accumulator

Abstract: HYDRO accumulates rainfall in real-time using data from the C-band radar.

Author: B. Wm. Folliott

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1978-08-01

Version: 1978-09-01

Source Language: PDP-11 FORTRAN

Related Programs: X Z Q M S

Name: REAL

Title: Real-time aircraft direction.

Abstract: REAL is an easy-to-use program capable of displaying real-time radar data and real-time aircraft positions on one display. Various features of the program assist the seeding aircraft controller in his work, while other program enhancements allow the detailed real-time display of radar data of interest to the research meteorologist. Users can also test for the presence of hail with the help of the built-in hail detector.

Author: John Ramsden, Reinhard Drobig

Originating Organization:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

Date Written: 1977-04-01

Version: 1978-08-01

Source Language: PDP-11 FORTRAN

Related Programs:

EXAMPLE OF A COMPLETE PROGRAM DOCUMENTATION

APPENDIX 2

IDENTIFICATION

NAME: AIRSCAL

TITLE: Plot aircraft tracks to scale

ABSTRACT: This program plots a selected aircraft track for a specified time interval at a specified scale.

AUTHOR: Reinhard Drobig

ORIGINATING ORGANIZATION:
Atmospheric Sciences Division
Alberta Research Council
Edmonton, Alberta, Canada

DATE WRITTEN: 1978-09-20

VERSION: 1978-09-20

SOURCE LANGUAGE: PDP-11 FORTRAN

RELATED PROGRAMS: AIRPLOT AIRPRNT

FUNCTION

NARRATIVE DESCRIPTION

This program first prompts the user interactively for the date on which the aircraft data were logged. The user is then prompted for information about the time interval to be plotted, the aircraft to be plotted, the center of the area to be displayed in radar coordinates, and the scale at which the track is to be plotted. Once this information has been obtained the aircraft log is scanned and all aircraft positions that fall within the display area and meet the criteria specified by the user, are then plotted on an 8½ by 11 inch piece of paper. The user is then prompted again for the next set of data.

METHODS

It is assumed that the input file is in chronological order.

LIMITS

The program is unable to distinguish between correct data and any data that was received incorrectly from the radar; therefore the plotted aircraft track may be erratic in places. The program does not warn the user about any data that fall outside the display area.

DATA INPUTS

The program reads the aircraft log file which contains the position of each aircraft. The position of an aircraft is recorded once every 10 seconds. The program also reads the user responses to its own prompts. The information read from the user terminal is two integer values representing the month and day. Further values read are an integer value indicating the aircraft number, two real values representing the center of the window in radar coordinates and one integer value indicating the scale of the plot to be produced. More details about these values can be found in the section Normal Operation.

MODE OF OPERATION

This program is interactive and can be run from any terminal. The plot is automatically produced on the Printer/Plotter. If this program is run on a graphics terminal, no plot is produced on the terminal.

OPTIONS

None

PRINTED OUTPUTS

None

GRAPHIC OUTPUT

The aircraft track is plotted as a number of triangles. The apex of each triangle shows the position of the aircraft at that time while the whole triangle points in the direction the aircraft was flying in at that time. The start of the aircraft track is marked by a cross (X) and the end is marked by a star (*). The radar range rings are plotted and various towns are plotted to serve as ground references.

OTHER OUTPUTS

The program produces a number of plot files with the help of the ASD graphics library. These files are output to the Printer/Plotter and are destroyed as soon as this has been done.

EXAMPLES

Figure 1 shows an example of a plot produced by program AIRSCAL

OPERATION

INPUTS

The program reads the logged aircraft data file to obtain the information required for the plots. The name of the file containing the logged aircraft data has the following format:

mmddAIR.DAT

where mm is the first and third character of the month in which the data was logged and dd is the day on which the

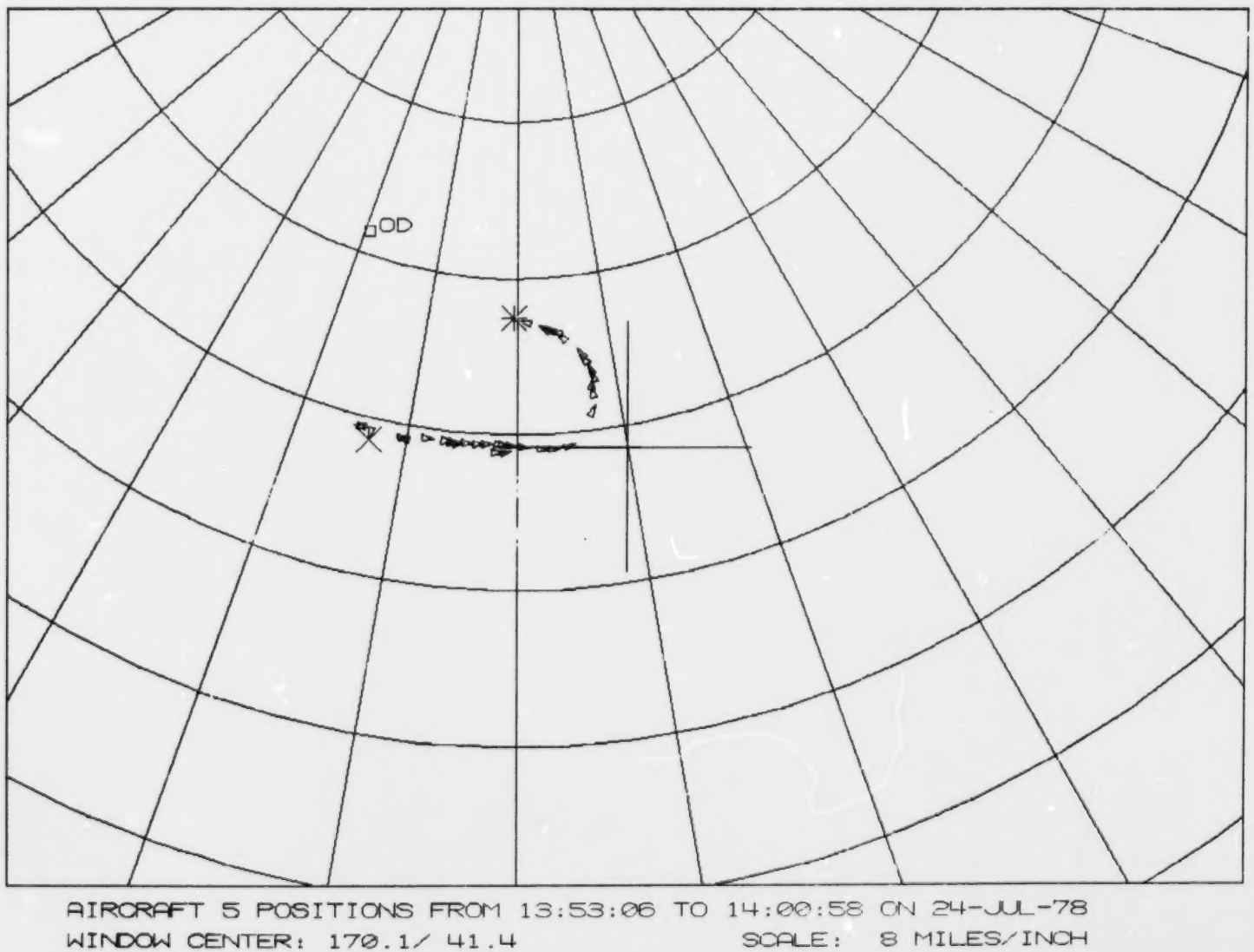
JL24AIR produced Thursday 16-OCT-80 11:51:50.8 by [201,005] TTI1 HBS Version 8.02. Enlargement 1. Resolution 2. Copy 1 of 1.
Plot Description File of 5 blocks created Thursday 16-OCT-80 11:51:24.7 by [201,005] TTI1 Using GSP Version 5.03.
OD
AIRCRAFT 5 POSITIONS FROM 13:53:06 TO 14:00:58 ON 24-JUL-78
WINDOW CENTER: 170.1/ 41.4
SCALE: 8 MILES/INCH

FIGURE 1. Example of a plot of aircraft tracks produced by program AIRSCAL.

data was logged. This data file contains one record for each aircraft position logged. The position of each aircraft is logged once every 10 seconds and the record has the following format:

CAAAAARRRRRHH:MM:SS

where

C is the aircraft code (0-9) preceded by a blank.

AAAAA This field contains the azimuth of the aircraft in system notation (Integer).

RRRRR is the range of the aircraft in system notation. This number is also an integer.

HH:MM:SS This is the time at which the aircraft position was logged.

The aircraft log file also contains records of the form

THIS FILE WAS STARTED ON DD-MMM-YY at HH:MM:SS

which are ignored by this program. The program also ignores any records that result in read errors.

OUTPUTS

For outputs see the section GRAPHIC OUTPUT.

Normal Operation

Once the program is running it will prompt for information required to produce the desired plot. The first question is:

ENTER MONTH AND DAY (MM,DD)>

to find out on what day the aircraft data was logged. Answer this question by typing in a number indicating the month followed by a number indicating the day on which the data was logged. The two numbers must be separated by a comma and the program assumes that these numbers are correct. As soon as you have typed in the numbers, press the carriage return key and the program will prompt you with the following message:

ENTER BEGINNING
AND ENDING TIME (HHMM,HHMM)>

Answer this question by typing in the time at which the aircraft track is to begin, followed by the time the aircraft track is to stop. The times have to be input in the 24 hour clock format and each time must be entered as one number, that is the time 23:13 would be typed in as *2313*. The two numbers must be separated by a comma. Press the carriage return key after having typed in the two numbers. The next question is:

ENTER AIRCRAFT NUMBER>

Enter the number of the aircraft whose track you want to have plotted, then press carriage return. This will cause the program to prompt you with the next question which is:

ENTER CENTER OF WINDOW (AAA.A,RRR.R)>

You answer this question by entering the azimuth *(AAA.A)* and the range *(RRR.R)* at which you want the center of the window located. The azimuth has to be entered in degrees and the range in statute miles. The two numbers must be separated by a comma. Press carriage return after you have typed in the numbers and the program will prompt you with the question:

ENTER NUMBER OF MILES TO THE INCH>

to which you must reply by typing in an integer, that is *1, 2,* or *8* but not 1.2 or 1.8. Press carriage return once you have answered the questions. The program will now produce the desired plot and will then prompt you again for input. If you do not wish any further output depress the CTRL-key and the Z-key simultaneously to stop the program, then go and collect your output.

ERROR MESSAGES AND ERROR RECOVERY

If a serious error occurs the program will stop. A less severe error causes the program to print an error message and the program will then start over again from the beginning.

The following paragraphs will attempt to explain the most likely causes underlying the error messages below.

FILE xxx NOT ON DISK

The characters xxx represent the filename which cannot be found. There may be a number of reasons for this message. First, check that you are signed on under the RADARSAVE account. If you are, ask the program maintainer to check into the problem.

AIRCRAFT x NOT LOGGED ON THIS DATE.

where x is the aircraft number specified by you. The message indicates that there is no data concerning the selected aircraft in the specified file. The error message is the result of having specified an incorrect aircraft number or a malfunction in the radar or aircraft equipment on that date.

NO DATA AVAILABLE FOR AIRCRAFT x
FROM xxxx HRS to xxxx HRS

The message indicates that the aircraft was either not flying during that period or that there was a malfunction of radar, computer, or aircraft equipment during this period of time.

AIRCRAFT x NOT IN RANGE DURING THIS TIME

This message indicates that the aircraft was outside the digitized radar range during this time period.

COMPUTER SYSTEM REQUIREMENTS

PERIPHERAL EQUIPMENT

To run this program you need the Printer/Plotter, any kind of terminal and a disk drive from which the data can be read.

SUPPORTING SOFTWARE

System Routines

ERRSET — This subroutine allows specification of the action to be taken when an error is detected by the OTS. The error action to be taken is specified individually for each error, independent of other errors. The general form of the call is:

CALL ERRSET (NUMBER, CONTIN, COUNT, TYPE, LOG, MAXLIM)

where

NUMBER is an integer value specifying the error number to which the following parameters apply.

CONTIN is Logical value specifying whether to continue after an error. TRUE means continue, FALSE means exit if this error occurs.

COUNT is a Logical value specifying whether to count this error against the task maximum error limit. TRUE means count, FALSE means don't count it.

TYPE is a logical value specifying the type of continuation to perform. TRUE means that an ERR = transfer is to be taken if available. If this action is indicated and an ERR = keyword is not specified in the I/O statement, then the task will exit when the error occurs. FALSE means return to the routine that detected the error for default error recovery.

LOG is a logical value specifying whether to produce an error message for this error. TRUE means produce message, FALSE means don't produce a message.

MAXLIM is a positive integer value used to set the task's maximum error limit. The default value is set to 31 at task initialization.

ASSIGN— The assign subroutine allows the association of filename information with a logical unit number. The ASSIGN call, if present, must be executed before the logical unit is opened for I/O operations (by READ or WRITE) for sequential access files, or before the associated DEFINE FILE statements for random-access files. The device assignment remains in effect until a new CALL ASSIGN is performed. The filename assignment remains in effect only until the file is closed by a CALL CLOSE. The call to ASSIGN has the general form:

CALL ASSIGN (N, NAME, ICNT)

where

N logical unit number expressed as in integer constant, variable, or expression.

NAME Hollerith or literal string constant containing any standard device/filename specification. If the device is not specified, then the device remains unchanged from the default assignments, or the MCR REASSIGN command. If a filename is not specified the FORTRAN default names are used.

ICNT specifies the number of characters in the string 'NAME'. If 'ICNT' is zero or unspecified, the string 'NAME' will be processed until the first null character (0) is encountered.

ATAN2 – This routine calculates the arctangent given the sides of the triangle which are opposite and adjacent to the angle for which the arctangent is to be calculated. This routine is different from other routines in that it will return the appropriate angle if the tangent is undefined.

R=ATAN2(0,A)

where

R is a real variable which will contain the angle in radians after the call.

O is a real variable which contains the length of the side opposing the angle to be calculated. The length is specified in user units.

A is a real variable which contains the length of the side adjoining the angle to be calculated. The length is specified in user units.

ERRSNS – The ERRSNS subroutine allows the user to obtain information about the most recent error that has occurred during program execution. The general form of the call is:

CALL ERRSNS (NUM, FCSERR, FCSER1, IUNIT)

where

NUM is an INTEGER*2 variable or array element into which will be stored the most recent error number. (A zero will be returned if no error has occurred.)

If the last error occurred as a result of an error indication from File Control Services, then the next three parameters will receive selected values from the file descriptor block (FDB). Otherwise, values of zero will be returned. Consult the I/O Operations Reference Manual for definitions of the interpretation of the FCS error return codes.

FCSERR is an INTEGER*2 variable or array element into which will be stored the F.ERR+1 field of the FDB.

FCSER1 is an INTEGER*2 variable or array element into which will be stored the F.ERR field of the FDB.

IUNIT is an INTEGER*2 variable or array element into which will be stored the logical unit number.

Calling ERRSNS without any arguments clears any errors that might have occurred.

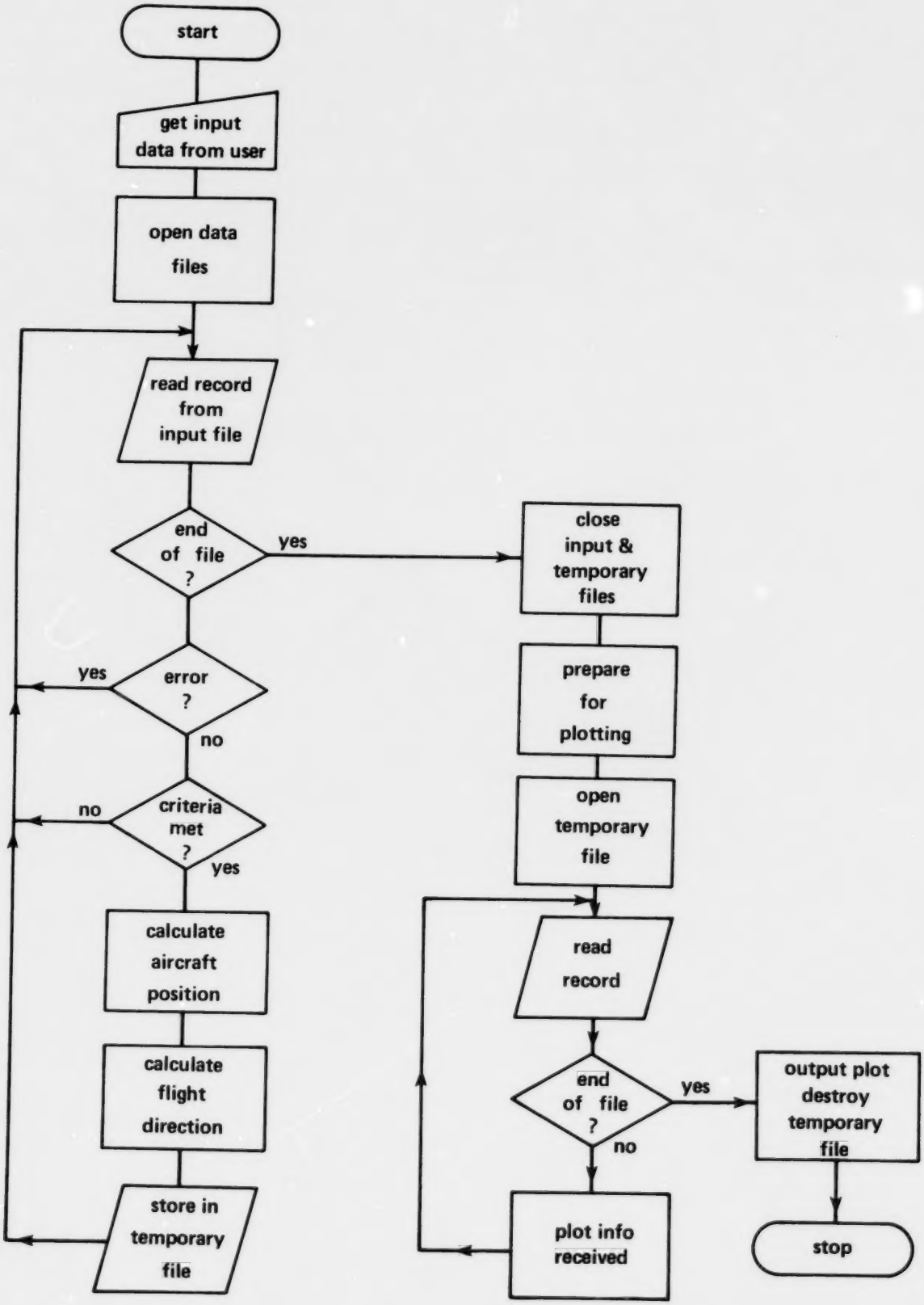

FIGURE 2. Flowchart for program ASCAL.

CLOSE — The CLOSE subroutine allows the currently open file on a logical unit to be closed. The form on the call is:

CALL CLOSE (N)

where N is an integer value specifying the logical unit.

DELETE — This routine will delete a file from disk provided the file is currently open. The routine is called as follows:

CALL DELETE (N,I)

where

N is an integer constant, variable or expression indicating the logical unit on which the file to be deleted has been opened.

I is an integer variable which will contain an error code returned from file control services. The variable is zero if there was no error. If the user is not interested in any error return codes he may omit this parameter.

SIN – This routine calculates the sine of an angle. The way to call this routine is: ***S=SIN(A)***

where

S is a real variable which will receive the sine.

A is a real variable which contains the angle in radians.

COS – This routine calculates the cosine of a given angle. The routine call is: ***S=COS(A)***

where

S is a real variable which will receive the cosine.

A is a real variable which contains the angle in radians.

Library Routines — See the radar library users' manual RADHOW for information on the routines:

ACON
PCONA
PCONR

See the ASD Graphics User's manual for information on the routines.

PLOTS
HARDON
ERASE
OFFSET
PLOT
TEXT
HRDCPY
STOLP

TOTAL PROGRAM SIZE

The FORTRAN source code consists of 377 statements and the program takes up 23552 words of memory at run time.

FILE SPECIFICATIONS

The aircraft position log is read by the program. The maximum record length in this file is 20 bytes. Each record is formatted and no special file operations are carried out. The temporary file is read and written using unformatted binary records. Each record is 24 bytes long.

ORIGINAL SYSTEM

The program was developed on a PDP-11/50 using the PDP-11 FORTRAN under the RSX-11M operating system. The program assumes that at least one terminal (any kind), one disk drive and one electrostatic Printer/Plotter are available.

INTERNAL FEATURES

PROGRAM STRUCTURE

DATA STRUCTURES

The program processes the data in two phases. During the first phase the program reads the input file and collects all the data that meet the user's specified criteria. This pre-processed data is stored in the file AIR.TMP from which it will be read for the second phase. The file is destroyed as soon as the program is finished with it.

The file is unformatted binary and each record is 24 bytes long. The record is structured as follows:

1 — 4 These bytes contain the binary representation of the floating point variable XC. XC is the X-coordinate of the aircraft position in the radar coordinate system.

5 — 8 These bytes contain the binary representation of the variable YC. YC is the Y-coordinate of the aircraft position in the radar coordinate system.

9 — 12 These bytes contain the binary representation of the variable A1. A1 contains an angle in radians. The angle is measured clockwise with respect to the X-axis and defines the left hand side of the triangle to be plotted (see GRAPHIC OUTPUT).

13 — 16 These bytes contain the binary representation of the variable A2. A2 contains an angle in radians. The angle is measured clockwise with respect to the X-axis and defines the right hand side of the triangle to be plotted (see GRAPHIC OUTPUT).

17 — 24 These bytes contain the time at which the particular aircraft position was logged in ASCII form.

COMMON BLOCKS

The program utilizes two common blocks named WINDOW and LMKCOM which are organized as follows:
Common Window

This common block is used by the routines that calculate and draw the polar window. These routines were extracted from a different program and as a consequence word 1 to word 6 of the common block are not used in this program. Word 7 is the first word of a REAL*4 array W which contains the window boundaries as follows:

W(1) This location contains the left boundary of the window. The boundary is specified in 5.0 metre units with respect to the radar.
W(2) This location contains the right boundary of the window. The boundary is specified in 5.0 metre units with respect to the radar.
W(3) This location contains the bottom boundary of the window. The boundary is specified in 5.0 metre units with respect to the radar.
W(4) This location contains the top boundary of the window. The boundary is specified in 5.0 meter units with respect to the radar.

The other common block in use is the LMKCOM block and is used only by the DRWLMK routine to plot the locations of major towns and cities in the project area. The block is defined as follows:

COMMON/LMKCOM/ITC, ITX, ITY, ITS, ITN

where

ITC is a 10 word integer array which contains two characters per word. Each pair of characters is used as a code to indicate what town or city is being drawn.
ITX is a 10 word integer array which contains the X-coordinate of the center of the town or city. The X-coordinate is given in 5 metre units with respect to the radar.
ITY is a 10 word integer array which contains the Y-coordinate of the center of the town or city. The Y-coordinate is given in 5 metre units with respect to the radar.
ITN is an integer which contains the actual number of land locations stored in the common block.

MODULE ARC

Function — The purpose of this routine is to draw an arc around an arbitrary origin.

Calling Sequence — The FORTRAN call is

CALL ARC (IA1, IA2, IR1, IXO, IYO, IAO, SCF)

Input — All the parameters except SCF are integer variables and are defined as follows:

IA1 The counterclockwise azimuth in tenth of degrees in the user defined polar grid.
IA2 The clockwise azimuth in tenth of degrees in the user defined polar grid.
IR1 The distance of the arc from the user defined polar grid origin in user defined units.
IXO This variable defines the X-coordinate of a point in the radar coordinate system and must be given in five metre units. The point defined by this variable is used as the origin of the user defined polar grid.
IYO This variable defines the Y-coordinate of a point in the radar coordinate system and must be given in five metre units. The point defined by this variable is used as the origin of the user defined polar grid.
IAO This variable indicates how far the user defined polar grid was rotated clockwise with respect to the radar coordinate system. This number must be given in tenth of degrees.
SCF This is a real variable indicating the number of five metre units that will fit into one user defined unit.

Output — None

MODULE CMPWND

Function — The purpose of this routine is to compute the smallest polar window which will surround a given rectangle.

Calling Sequence — ***CALL CMPWND (W, IP, IXO, IYO, IAO, SCF)***

Input —

W is a REAL*4 array containing the boundaries for the rectangular window. The format of this array has been described in the section on common blocks.
IXO is an integer which specifies the X-coordinate of the user defined grid origin in terms of the radar coordinate system. X is specified in 5 metre units.
IAO is an integer which specifies the number of tenth of degrees the user defined grid has been rotated clockwise with respect to the radar grid.
SCF is a real variable which contains the number of 5 metre units that make up a user defined unit.

Output —

IP is an integer array which contains the counter clockwise azimuth, the clockwise azimuth, the bottom range and the top range of the smallest polar window that will surround the given rectangle. The azimuth and ranges are given in terms of the user defined polar grid. The azimuth are given in tenth of degrees.

MODULE CPLOT

Function — The purpose of this routine is to draw lines and clip them to the display window.

Calling Sequence — ***CALL CPLOT (X, Y, IC)***

Input — This routine is similar to the call to plot. Three variables are required as follows:

X This variable is of type real and contains the X-coordinate of the point to which the pen is to move.

Y This variable is of type real and contains the Y-coordinate of the point to which the pen is to move.

IC This variable is of type integer and contains a code which indicates whether the pen is to be moved to the point or whether a line is to be plotted to that point as follows:

2 This indicates that a line is to be plotted from the current position of the pen to the point given.

3 This value indicates that the pen is to be moved to the given position without plotting anything.

The routine accesses the common block WINDOW for information on the window boundaries.

Output— There are no output parameters for this routine.

MODULE CROSS

Function — The purpose of this routine is to draw a cross of a specified size.

Calling Sequence — ***CALL CROSS (X, Y, S)***

Input —

X is a real variable which contains the X-coordinate of the center of the cross in 5 metre units.

Y is a real variable which contains the Y-coordinate of the center of the cross in 5 metre units.

S is a real variable which contains the size of the cross in user units.

Output — None

MODULE DRWLMK

Function — The purpose of this routine is to draw a number of squares on the display, each of which represents a major town or city in the project area.

Calling Sequence — ***CALL DRWLMK***

Input — This routine receives all its data through the common block LMKCOM.

Output — None

MODULE DRWRDL

Function — This routine draws radial lines for a specified polar window in a user specified polar grid.

Calling Sequence — ***CALL DRWRDL (IL, IR, IB, IT, IN, IX, IY, IO, SC)***

Input — All parameters are input parameter and have the following purpose:

IL is an integer variable specifying the counter clockwise azimuth of the polar window in tenth of degrees. The azimuth must be specified in the user defined polar coordinate system.

IR is an integer variable specifying the clockwise azimuth of the polar window in tenth of degrees. The azimuth must be specified in the user defined polar coordinate system.

IB is an integer variable specifying the bottom range of the polar window in user defined units.

IT is an integer variable specifying the top range of the polar window in user defined units.

IN is an integer variable which indicates how many tenth of degrees apart the radial lines are to be spaced. Radial lines are drawn at every azimuth that is a multiple of the number specified in IN and falls within the window boundaries specified. The radial lines are drawn using user coordinates.

IX is an integer variable specifying the X-coordinate of the user defined grid origin in five metre units with respect to the radar.

IY is an integer variable specifying the Y-coordinate of the user defined grid origin in five metre units with respect to the radar.

IO is an integer variable specifying in tenth of degrees the amount the user defined grid has been rotated with respect to the radar grid. A positive value indicates clockwise rotation and a negative value indicates counter-clockwise rotation.

SC is a real variable which contains the number of five metre units that make up one user defined unit.

Output — None

MODULE DRWRGR

Function — The purpose of this routine is to draw range rings at specified intervals in a specified polar window. A user defined grid is used for this operation.

Calling Sequence — ***CALL DRWRGR (IL, IR, IB, IT, IN, IX, IY, IO, SC)***

Input — All parameters are input parameters which have the following purpose:

IL is an integer variable containing the counter-clockwise azimuth of the polar window in tenth of degrees. The azimuth is assumed to be given in the user defined polar coordinate system.

IR is an integer variable containing the clockwise azimuth of the polar window in tenth of degrees. The azimuth is assumed to be given in the user defined polar coordinate system.

IB is an integer variable which contains the bottom range of the polar window in user defined units.

IT is an integer variable which contains the top range of the polar window in user defined units.

IN is an integer specifying the interval between range rings in user defined units. Range rings are drawn at every unit that is a multiple of the number specified in IN provided that the range ring is within the polar window.

IX is an integer variable specifying the X-coordinate of the user defined polar grid origin in five metre units with respect to the radar.

IY is an integer variable specifying the Y-coordinate of the user defined polar grid origin in five metre units with respect to the radar.

IO is an integer variable specifying in tenth of degrees the amount the user defined polar grid has been rotated with respect to the radar polar grid. A positive number indicates clockwise rotation, a negative number indicates counter-clockwise rotation.

SC is a real variable which contains the number of five metre units that make up one user defined unit.

Output — None

INSTALLATION INSTRUCTIONS

DEVICES

To run this program one disk drive, one terminal (any kind) and the Printer/Plotter are required.

LOCATION OF SUPPORTING SOFTWARE

The subroutine libraries GRAPHICS, LIBRARY and RADAR are located on DM1 under the user identification code (111,1). The object code for the main program and the program modules not in the library are assumed to reside on the device SY: and under the current UIC.

OPERATING-SYSTEM COMMANDS

See INDIRECT COMMAND FILES below

INDIRECT COMMAND FILES

To compile the object modules required issue the command

@ [203,100]ASCALASM

which will execute the indirect command file that generates the required object code.

The task is then built by using the indirect command file

@ [203,100]ASCALTKB.CMD

which will leave the built task under the current UIC on the default device.

Overlay Structure Description

This program is not overlaid.

TASK FILE LOCATION

If the above mentioned indirect command file is used the task will be left under whatever UIC the task was built. The task will then reside on the default device for that User Identification Code.

OPERATING INSTRUCTIONS

SET-UP PROCEDURES

Before this program can be run the Printer/Plotter has to be turned on. After this has been done sign on to the computer by typing

HELLO RADARSAVE

and then press the carriage return key. You will be prompted for a password to which you reply by pressing the carriage return key. The computer will respond to this by typing out a number of messages at your terminal followed by a prompt such as

>

which indicates that the computer is now ready to accept commands. See the section on Operating System Commands on how to get the program running.

Location of Input Files — The input files are usually located under the Radarsave account. However, the files must be transferred to the account from another computer which is done by the system staff and it is therefore recommended to always check with the system staff to insure that the desired files are actually ready to be used. If the files are stored under the Radarsave account they will reside on DM1:.

RUNNING PROCEDURES

Operating System Commands — To run the program type

RUN DM1:[210,3]AIRSCAL

which is all that is needed to get the program started.

Indirect Command Files — None

TAKE DOWN PROCEDURES

Once the program terminates collect the plotted output from the Printer/Plotter then type at your terminal:

BYE

and that will complete the take down procedure.

LABELLING AND DISPOSITION OF OUTPUT

Not applicable

NAME OF PROGRAM MAINTAINER

Reinhard Drobig

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 13:54:25
CORE=14K, UIC=[203,100]                          ,AIRSCAL/-SP=AIRSCAL

      C
      C THE PURPOSE OF THIS PROGRAM IS TO DRAW AIRCRAFT
      C POSITIONS. THE USER SELECTS THE CENTER OF THE WINDOW
      C THE AIRCRAFT TO BE PLOTTED, THE PLOTTING SCALE, THE DATE
      C AND TIME INTERVAL. USING THIS INFORMATION THE PROGRAM PRODUCES
      C AN 8 1/2 BY 11 INCH PLOT.
      C
0001          LOGICAL*1 FIRST,TIM(8),TIMP(8),TIMF(8),STRNG(59),FILE(15)
0002          LOGICAL*1 BLNK,ZERO
0003          INTEGER IP(4),ITC(10),ITX(10),ITY(10),ITS(10),ITN,MONTH(2,12)
0004          REAL*4 SMON(12),W(4)
      C
0005          COMMON /WINDOW/ A,B,C,W
0006          COMMON /LMKCOM/ ITC,ITX,ITY,ITS,ITN
      C
0007          EQUIVALENCE (SMON,MONTH)
      C
0008          DATA BLNK/' '/,ZERO/'0'/,ITN/7/
0009          DATA ITC/'RM','WK','CG','ED','RB','OD','DM',3*'  '/
0010          DATA ITX/-14178,6834,-2550,5100,-4801,-3060,16524,0,0,0/
0011          DATA ITY/4488,17646,-25704,30294,10318,-8670,-16116,0,0,0/
0012          DATA ITS/204,510,4080,3570,204,204,408,0,0,0/
0013          DATA SMON/'JAN ','FEB ','MAR ','APR ','MAY ','JUN ',
             *          'JUL ','AUG ','SEP ','OCT ','NOV ','DEC '/
      C
0014  1000    FORMAT ('$ENTER MONTH AND DAY (MM,DD) > ')
0015  1001    FORMAT ('$ENTER BEGINNING AND ENDING TIME (HHMM,HHMM) > ')
0016  1002    FORMAT ('$ENTER AIRCRAFT NUMBER > ')
0017  1003    FORMAT ('$ENTER CENTER OF WINDOW (AAA.A,RRR.R) > ')
0018  1004    FORMAT ('$ENTER NUMBER OF MILES TO THE INCH > ')
0019  1005    FORMAT ('SY0:'2A1,I2,'AIR.DAT')
0020  1007    FORMAT (' *** FILE ',15A1,' NOT ON DISK')
0021  1008    FORMAT (' *** AIRCRAFT ',I1,' NOT LOGGED ON THIS DATE')
0022  1009    FORMAT (' *** NO DATA AVAILABLE FOR AIRCRAFT ',I1,/,
             *    ' *** FROM ',I4,' HRS TO ',I4,' HRS ')
0023  1010    FORMAT (' *** AIRCRAFT ',I1,' NOT IN RANGE DURING THIS TIME')
0024  1012    FORMAT ('AIRCRAFT ',I1,' POSITIONS FROM ',8A1,' TO ',8A1,
             *    ' ON ',I2,'-',1A3,'-78')
0025  1013    FORMAT ('WINDOW CENTER: ',F5.1,'/',F5.1,13X,'SCALE: ',I2,
             *    ' MILES/INCH')
0026  2000    FORMAT (2I7)
0027  2001    FORMAT (2I7)
0028  2002    FORMAT (I7)
0029  2003    FORMAT (2F7.1)
0030  2004    FORMAT (I7)
0031  2006    FORMAT (1X,I1,2I5,8A1)
0032  2011    FORMAT (I2,1X,I2)
      C
0033          CALL ERRSET(29,,.FALSE.,,.FALSE.)
0034          CALL ERRSET(64,,.FALSE.,,.FALSE.)
0035  10      XP=0.0
0036          YP=0.0
0037          IAIRC=0
0038          IAIRT=0
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 13:54:25
CORE=14K, UIC=[203,100]                          ,AIRSCAL/-SP=AIRSCAL

0039          IAIRIR=0
0040          WRITE (5,1000)
0041          READ (5,2000,END=999) IMON,IDAY
0042          WRITE (5,1001)
0043          READ (5,2001,END=999) ITIM1,ITIM2
0044          WRITE (5,1002)
0045          READ (5,2002,END=999) IAIR
0046          WRITE (5,1003)
0047          READ (5,2003,END=999) WAZ,WRG
0048          WRITE (5,1004)
0049          READ (5,2004,END=999) ISCAL
0050          ENCODE (15,1005,FILE)(MONTH(I,IMON),I=1,2),IDAY
0051          IF (FILE(7).EQ.BLNK) FILE(7)=ZERO
0053          CALL ASSIGN (4,'AIR.TMP',7)
0054          CALL ASSIGN (7,FILE,15)
0055    20    READ(7,2006,ERR=30,END=40)IAR,IAZ,IRG,(TIM(I),I=1,8)
0056          IF (IAR.NE.IAIR) GOTO 20
0058          IAIRC=IAIRC+1
0059          DECODE(5,2011,TIM)IHRS,IMIN
0060          ITIM=IHRS*100+IMIN
0061          IF (ITIM.LT.ITIM1) GOTO 20
0063          IF (ITIM.GT.ITIM2) GOTO 20
0065          IAIRT=IAIRT+1
0066          CALL ACON(IAZ)
0067          CALL PCONA (IAZ,IRG,IX,IY)
0068          IF (IX.EQ.0.AND.IY.EQ.0) GOTO 20
0070          IAIRIR=IAIRIR+1
0071          XC=IX
0072          YC=IY
0073          A1=ATAN2(XC-XP,YC-YP)
0074          A2=A1+0.2618
0075          A1=A1-0.2618
0076          WRITE(4) XC,YC,A1,A2,(TIM(I),I=1,8)
0077          XP=XC
0078          YP=YC
0079          GOTO 20
0080    30    CALL ERRSNS (IERR)
0081          IF (IERR.EQ.64) GOTO 20
0083          IF (IERR.NE.29) STOP 'ABNORMAL PRESCAN'
0085          WRITE (5,1007)(FILE(I),I=1,15)
0086          CALL CLOSE (7)
0087          CALL DELETE (4)
0088          GOTO 10
0089    40    CALL CLOSE(7)
0090          REWIND 4
0091          IF (IAIRC.GT.5) GOTO 50
0093          WRITE (5,1008) IAIR
0094          CALL DELETE (4)
0095          GOTO 10
0096    50    IF (IAIRT.GT.0) GOTO 60
0098          WRITE (5,1009) IAIR,ITIM1,ITIM2
0099          CALL DELETE (4)
0100          GOTO 10
0101    60    IF (IAIRIR.GT.0) GOTO 70
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 13:54:25
CORE=14K, UIC=[203,100]                          ,AIRSCAL/-SP=AIRSCAL

0103          WRITE (5,1010) IAIR
0104          CALL DELETE (4)
0105          GOTO 10
0106    70    SCALE=ISCAL*200.0*1.609344
0107          IWAZT=WAZ*10.0
0108          IWRGT=WRG*200.0*1.609344
0109          CALL PCONR (IWAZT,IWRGT,IX,IY)
0110          W(1)=IX-5.0*SCALE
0111          W(2)=IX+5.0*SCALE
0112          W(3)=IY-3.5*SCALE
0113          W(4)=IY+3.5*SCALE
0114          CALL CMPWND (W,IP,0,0,0,1.0)
0115          IP(3)=MAX0(3218,IP(3))
0116          XF=400.0/SCALE
0117          YF=XF
0118          XO=-W(1)
0119          YO=200.0/YF-W(3)
0120          WXC=W(1)+(W(2)-W(1))/2.0
0121          WYC=W(3)+(W(4)-W(3))/2.0
0122          SIZE=SCALE/10.0
0123          FIRST=.TRUE.
0124          CALL PLOTS
0125          CALL HARDON(3)
0126          CALL ERASE
0127          CALL OFFSET (XO,XF,YO,YF)
0128          CALL CROSS (WXC,WYC,SCALE*2)
0129          CALL PLOT(W(1),W(4),3)
0130          CALL PLOT(W(2),W(4),2)
0131          CALL PLOT(W(2),W(3),2)
0132          CALL PLOT(W(1),W(3),2)
0133          CALL PLOT(W(1),W(4),2)
0134          CALL DRWLMK
0135          CALL DRWRDL(IP(1),IP(2),IP(3),IP(4),100,0,0,0,1.0)
0136          CALL DRWRGR(IP(1),IP(2),IP(3),IP(4),3218,0,0,0,1.0)
0137          READ (4) XP,YP,AP1,AP2,(TIMP(I),I=1,8)
0138    80    IF (.NOT.FIRST) GOTO 90
0140          IF (XP.LT.W(1).OR.XP.GT.W(2)) GOTO 85
0142          IF (YP.LT.W(3).OR.YP.GT.W(4)) GOTO 85
0144          CALL PLOT (XP+SIZE,YP+SIZE,3)
0145          CALL PLOT (XP-SIZE,YP-SIZE,2)
0146          CALL PLOT (XP+SIZE,YP-SIZE,3)
0147          CALL PLOT (XP-SIZE,YP+SIZE,2)
0148    85    DO 100 I=1,8
0149    100   TIMF(I)=TIMP(I)
0150          FIRST=.FALSE.
0151    90    READ (4,END=110) XC,YC,A1,A2,(TIM(I),I=1,8)
0152          XT1=XP-SIN(AP1)*SIZE
0153          YT1=YP-COS(AP1)*SIZE
0154          XT2=XP-SIN(AP2)*SIZE
0155          YT2=YP-COS(AP2)*SIZE
0156          IF (XP.LT.W(1).OR.XP.GT.W(2)) GOTO 130
0158          IF (YP.LT.W(3).OR.YP.GT.W(4)) GOTO 130
0160          CALL PLOT (XP,YP,3)
0161          CALL PLOT (XT1,YT1,2)
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 13:54:25
CORE=14K, UIC=[203,100]                              ,AIRSCAL/-SP=AIRSCAL

0162            CALL PLOT (XT2,YT2,2)
0163            CALL PLOT (XP,YP,2)
0164   130      DO 120 I=1,8
0165   120      TIMP(I)=TIM(I)
0166            XP=XC
0167            YP=YC
0168            AP1=A1
0169            AP2=A2
0170            GOTO 90
0171   110      CALL PLOT (XP+SIZE,YP+SIZE,3)
0172            CALL PLOT (XP-SIZE,YP-SIZE,2)
0173            CALL PLOT (XP+SIZE,YP-SIZE,3)
0174            CALL PLOT (XP-SIZE,YP+SIZE,2)
0175            CALL PLOT (XP+SIZE,YP,3)
0176            CALL PLOT (XP-SIZE,YP,2)
0177            CALL PLOT (XP,YP+SIZE,3)
0178            CALL PLOT (XP,YP-SIZE,2)
0179            ENCODE (59,1012,STRNG) IAIR,(TIMF(I),I=1,8),
               *    (TIMP(I),I=1,8),IDAY,SMON(IMON)
0180            CALL OFFSET (0.0,1.0,0.0,1.0)
0181            CALL TEXT (200.0,100.0,59,STRNG)
0182            ENCODE (59,1013,STRNG)WAZ,WRG,ISCAL
0183            CALL TEXT (200.0,0.0,59,STRNG)
0184            CALL HRDCPY
0185            CALL STOLP
0186            CALL DELETE (4)
0187            GOTO 10
0188   999      STOP
0189            END
```

FORTRAN IV STORAGE MAP

NAME	OFFSET	ATTRIBUTES
TIM	000006	LOGICAL*1 ARRAY (8)
TIMP	000016	LOGICAL*1 ARRAY (8)
TIMF	000026	LOGICAL*1 ARRAY (8)
STRNG	000036	LOGICAL*1 ARRAY (59)
FILE	000131	LOGICAL*1 ARRAY (15)
IP	000150	INTEGER*2 ARRAY (4)
MONTH	000160	INTEGER*2 ARRAY (2,12)
SMON	000160	REAL*4 ARRAY (12)
FIRST	001444	LOGICAL*1 VARIABLE
BLNK	000240	LOGICAL*1 VARIABLE
ZERO	000241	LOGICAL*1 VARIABLE
ERRSET	000000	REAL*4 PROCEDURE
XP	001446	REAL*4 VARIABLE
YP	001452	REAL*4 VARIABLE
IAIRC	001456	INTEGER*2 VARIABLE
IAIRT	001460	INTEGER*2 VARIABLE
IAIRIR	001462	INTEGER*2 VARIABLE
IMON	001464	INTEGER*2 VARIABLE
IDAY	001466	INTEGER*2 VARIABLE
ITIM1	001470	INTEGER*2 VARIABLE
ITIM2	001472	INTEGER*2 VARIABLE
IAIR	001474	INTEGER*2 VARIABLE
WAZ	001476	REAL*4 VARIABLE
WRG	001502	REAL*4 VARIABLE
ISCAL	001506	INTEGER*2 VARIABLE
I	001510	INTEGER*2 VARIABLE
ASSIGN	000000	REAL*4 PROCEDURE
IAR	001512	INTEGER*2 VARIABLE
IAZ	001514	INTEGER*2 VARIABLE
IRG	001516	INTEGER*2 VARIABLE
IHRS	001520	INTEGER*2 VARIABLE
IMIN	001522	INTEGER*2 VARIABLE
ITIM	001524	INTEGER*2 VARIABLE
ACON	000000	REAL*4 PROCEDURE
PCONA	000000	REAL*4 PROCEDURE
IX	001526	INTEGER*2 VARIABLE
IY	001530	INTEGER*2 VARIABLE
XC	001532	REAL*4 VARIABLE
YC	001536	REAL*4 VARIABLE
A1	001542	REAL*4 VARIABLE
ATAN2	000000	REAL*4 PROCEDURE
A2	001546	REAL*4 VARIABLE
ERRSNS	000000	REAL*4 PROCEDURE
IERR	001552	INTEGER*2 VARIABLE
CLOSE	000000	REAL*4 PROCEDURE
DELETE	000000	REAL*4 PROCEDURE
SCALE	001554	REAL*4 VARIABLE
IWAZT	001560	INTEGER*2 VARIABLE
IWRGT	001562	INTEGER*2 VARIABLE
PCONR	000000	REAL*4 PROCEDURE
CMPWND	000000	REAL*4 PROCEDURE
MAXO	000000	INTEGER*2 PROCEDURE

```
FORTRAN IV        STORAGE MAP

NAME      OFFSET  ATTRIBUTES

XF        001564  REAL*4      VARIABLE
YF        001570  REAL*4      VARIABLE
XO        001574  REAL*4      VARIABLE
YO        001600  REAL*4      VARIABLE
WXC       001604  REAL*4      VARIABLE
WYC       001610  REAL*4      VARIABLE
SIZE      001614  REAL*4      VARIABLE
PLOTS     000000  REAL*4      PROCEDURE
HARDON    000000  REAL*4      PROCEDURE
ERASE     000000  REAL*4      PROCEDURE
OFFSET    000000  REAL*4      PROCEDURE
CROSS     000000  REAL*4      PROCEDURE
PLOT      000000  REAL*4      PROCEDURE
DRWLMK    000000  REAL*4      PROCEDURE
DRWRDL    000000  REAL*4      PROCEDURE
DRWRGR    000000  REAL*4      PROCEDURE
AP1       001620  REAL*4      VARIABLE
AP2       001624  REAL*4      VARIABLE
XT1       001630  REAL*4      VARIABLE
SIN       000000  REAL*4      PROCEDURE
YT1       001634  REAL*4      VARIABLE
COS       000000  REAL*4      PROCEDURE
XT2       001640  REAL*4      VARIABLE
YT2       001644  REAL*4      VARIABLE
TEXT      000000  REAL*4      PROCEDURE
HRDCPY    000000  REAL*4      PROCEDURE
STOLP     000000  REAL*4      PROCEDURE

COMMON BLOCK /WINDOW/   LENGTH 000034

A         000000  REAL*4      VARIABLE
B         000004  REAL*4      VARIABLE
C         000010  REAL*4      VARIABLE
W         000014  REAL*4      ARRAY (4)

COMMON BLOCK /LMKCOM/   LENGTH 000122

ITC       000000  INTEGER*2 ARRAY (10)
ITX       000024  INTEGER*2 ARRAY (10)
ITY       000050  INTEGER*2 ARRAY (10)
ITS       000074  INTEGER*2 ARRAY (10)
ITN       000120  INTEGER*2 VARIABLE
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 13:54:52
CORE=14K, UIC=[203,100]                                  ,ARC/-SP=ARC

0001          SUBROUTINE ARC (IA1,IA2,IR1,IXO,IYO,IAO,SCF)
0002          A=ICLEAR(IA2-IA1)
0003          R1=IR1
0004          IF (A.EQ.0.0) A = 3600
0006          N=1
0007    18    IF (A.LE.50.0) GOTO 20
0009          A = A/2
0010          N = N+N
0011          GOTO 18
0012    20    A1 = IA1  + IAO
0013          CALL PLOTR (A1,R1,3,IXO,IYO,SCF)
0014          DO 30 I=1,N
0015          A1 = A1 + A
0016    30    CALL PLOTR (A1,R1,2,IXO,IYO,SCF)
0017          CALL PLOTR (FLOAT(IA2+IAO),R1,2,IXO,IYO,SCF)
0018          RETURN
0019          END
```

```
                FORTRAN IV      STORAGE MAP

                NAME    OFFSET  ATTRIBUTES

                IA1     000014  INTEGER*2 PARAMETER VARIABLE
                IA2     000016  INTEGER*2 PARAMETER VARIABLE
                IR1     000020  INTEGER*2 PARAMETER VARIABLE
                IXO     000022  INTEGER*2 PARAMETER VARIABLE
                IYO     000024  INTEGER*2 PARAMETER VARIABLE
                IAO     000026  INTEGER*2 PARAMETER VARIABLE
                SCF     000030  REAL*4    PARAMETER VARIABLE
                A       000036  REAL*4    VARIABLE
                ICLEAR  000000  INTEGER*2 PROCEDURE
                R1      000042  REAL*4    VARIABLE
                N       000046  INTEGER*2 VARIABLE
                A1      000050  REAL*4    VARIABLE
                PLOTR   000000  REAL*4    PROCEDURE
                I       000054  INTEGER*2 VARIABLE
                FLOAT   000000  REAL*4    PROCEDURE
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 13:54:51
CORE=14K, UIC=[203,100]                                  ,ARC/-SP=ARC

      C
0001          SUBROUTINE PLOTR (A,R,IP,IXO,IYO,SCF)
0002          X=R*SIN(A*1.745329E-3)*SCF+IXO
0003          Y=R*COS(A*1.745329E-3)*SCF+IYO
0004          CALL CPLOT (X,Y,IP)
0005          RETURN
0006          END
```

```
                FORTRAN IV      STORAGE MAP

                NAME    OFFSET  ATTRIBUTES

                A       000014  REAL*4    PARAMETER VARIABLE
                R       000016  REAL*4    PARAMETER VARIABLE
                IP      000020  INTEGER*2 PARAMETER VARIABLE
                IXO     000022  INTEGER*2 PARAMETER VARIABLE
                IYO     000024  INTEGER*2 PARAMETER VARIABLE
                SCF     000026  REAL*4    PARAMETER VARIABLE
                X       000034  REAL*4    VARIABLE
                SIN     000000  REAL*4    PROCEDURE
                Y       000040  REAL*4    VARIABLE
                COS     000000  REAL*4    PROCEDURE
                CPLOT   000000  REAL*4    PROCEDURE


FORTRAN IV      V01C-03C        THU 11-JAN-79 13:57:55
CORE=14K, UIC=[203,100]                                ,CMPWND/-SP=CMPWND

0001          SUBROUTINE CMPWND(WI,IP,IXO,IYO,IAO,SCF)
0002          INTEGER IQUAD(3,3),IAX(9),IBX(9),IWNDX(9,4)
0003          INTEGER IP(4)
0004          REAL*4 WI(4)
0005          DATA IQUAD/3,2,1,6,5,4,9,8,7/
0006          DATA IWNDX  /2,2,3,1,8,3,1,4,4,
             *                4,1,1,4,9,2,3,3,2,
             *                1,6,2,5,8,5,4,6,3,
             *                3,7,4,7,7,7,2,7,1/
0007          WL=WI(1)-IXO
0008          WR=WI(2)-IXO
0009          WB=WI(3)-IYO
0010          WT=WI(4)-IYO
0011          XMIN=WL
0012          IF (ABS(WR).LT.ABS(WL)) XMIN=WR
0014          YMIN=WB
0015          IF (ABS(WT).LT.ABS(WB)) YMIN=WT
0017          CALL XYCONX (IAX(1),IBX(1),WL,WT,IAO,SCF)
0018          CALL XYCONX (IAX(2),IBX(2),WR,WT,IAO,SCF)
0019          CALL XYCONX (IAX(3),IBX(3),WR,WB,IAO,SCF)
0020          CALL XYCONX (IAX(4),IBX(4),WL,WB,IAO,SCF)
0021          CALL XYCONX (IAX(5),IBX(5),XMIN,0,IAO,SCF)
0022          CALL XYCONX (IAX(6),IBX(6),0,IYMIN,IAO,SCF)
0023          IAX(7)=0
0024          IBX(7)=MAXO(IBX(1),IBX(2),IBX(3),IBX(4))
0025          IAX(8)=1351
0026          IBX(8)=0
0027          IAX(9)=1350
0028          IBX(9)=0
0029          IXP=2
0030          IYP=2
0031          IF (WR.LE.0) IXP=1
0033          IF (WL.GE.0) IXP=3
0035          IF (WT.LE.0) IYP=1
0037          IF (WB.GE.0) IYP=3
0039          IQ=IQUAD(IXP,IYP)
0040          IP(1)=IAX(IWNDX(IQ,1))
0041          IP(2)=IAX(IWNDX(IQ,2))
0042          IP(3)=IBX(IWNDX(IQ,3))
0043          IP(4)=IBX(IWNDX(IQ,4))
0044          RETURN
0045          END
```

```
FORTRAN IV       STORAGE MAP

NAME     OFFSET   ATTRIBUTES

IQUAD    000030   INTEGER*2 ARRAY (3,3)
IAX      000052   INTEGER*2 ARRAY (9)
IBX      000074   INTEGER*2 ARRAY (9)
IWNDX    000116   INTEGER*2 ARRAY (9,4) VECTORED
IP       000016   INTEGER*2 PARAMETER ARRAY (4)
WI       000014   REAL*4     PARAMETER ARRAY (4)
IXO      000020   INTEGER*2 PARAMETER VARIABLE
IYO      000022   INTEGER*2 PARAMETER VARIABLE
IAO      000024   INTEGER*2 PARAMETER VARIABLE
SCF      000026   REAL*4     PARAMETER VARIABLE
WL       000240   REAL*4     VARIABLE
WR       000244   REAL*4     VARIABLE
WB       000250   REAL*4     VARIABLE
WT       000254   REAL*4     VARIABLE
XMIN     000260   REAL*4     VARIABLE
ABS      000000   REAL*4     PROCEDURE
YMIN     000264   REAL*4     VARIABLE
XYCONX   000000   REAL*4     PROCEDURE
IYMIN    000270   INTEGER*2 VARIABLE
MAXO     000000   INTEGER*2 PROCEDURE
IXP      000272   INTEGER*2 VARIABLE
IYP      000274   INTEGER*2 VARIABLE
IQ       000276   INTEGER*2 VARIABLE
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 13:58:16
CORE=14K, UIC=[203,100]                                ,CPLOT/-SP=CPLOT

0001          SUBROUTINE CPLOT(X,Y,IC)
0002          COMMON /WINDOW/ CX,CY,SIZ,WL,WR,WB,WT,IA1,IA2,
             *    IB1,IB2,IAC,IRC,IR1,IR2,IWW,XP,YP,ICP
0003          ASSIGN 20 TO IHELL
0004          ISWP=0
0005          X1=X
0006          Y1=Y
      C-------CODE UP THE POINT
0007  10      IC1=0
0008          IF (X1.LT.WL) IC1=1
0010          IF (X1.GT.WR) IC1=2
0012          IF (Y1.LT.WB) IC1=4
0014          IF (Y1.GT.WT) IC1=8
0016          GOTO IHELL
      C-------SWAP POINTS
0017  50      ISWP=ISWP+1
0018          W=X1
0019          X1=X2
0020          X2=W
0021          W=Y1
0022          Y1=Y2
0023          Y2=W
0024          IW=IC1
0025          IC1=IC2
0026          IC2=IW
0027          GOTO IHELL
0028  20      X2=XP
0029          Y2=YP
0030          IC2=ICP
0031          ICO=ICP
0032          XP=X1
0033          YP=Y1
0034          ICP=IC1
0035          IF (IC.EQ.3.AND.ICP.EQ.0) CALL PLOT(X1,Y1,3)
0037          IF (IC.EQ.3) RETURN
0039  110     IF (IC1.NE.0.OR.IC2.NE.0) GOTO 30 !NOT TRIVIAL ACCEPT
0041          IF (MOD(ISWP,2).EQ.0) GOTO 40 !ORIGINAL ORDER IN TACT
0043          ASSIGN 40 TO IHELL
0044          GOTO 50
0045  40      IF (ICO.NE.0) CALL PLOT(X2,Y2,3)
0047          CALL PLOT (X1,Y1,2)
0048          RETURN
0049  30      IF (IC1.AND.IC2) RETURN !TRIVIAL REJECT
0051          ASSIGN 60 TO IHELL
0052          GOTO 50
0053  60      IF (.NOT.(IC1.AND.1)) GOTO 70
      C-------PUSH TOWARD LEFT EDGE
0055          Y1=Y1+(Y2-Y1)*(WL-X1)/(X2-X1)
0056          X1=WL
0057  70      IF (.NOT.(IC1.AND.2)) GOTO 80
      C-------PUSH TOWARD RIGHT EDGE
0059          Y1=Y1+(Y2-Y1)*(WR-X1)/(X2-X1)
0060          X1=WR
0061  80      IF (.NOT.(IC1.AND.4)) GOTO 90
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 13:58:16
CORE=14K, UIC=[203,100]                                ,CPLOT/-SP=CPLOT

      C-------PUSH TOWARD BOTTOM EDGE
0063          X1=X1+(X2-X1)*(WB-Y1)/(Y2-Y1)
0064          Y1=WB
0065  90      IF (.NOT.(IC1.AND.8)) GOTO 100
      C-------PUSH TOWARD TOP EDGE
0067          X1=X1+(X2-X1)*(WT-Y1)/(Y2-Y1)
0068          Y1=WT
0069  100     ASSIGN 110 TO IHELL
0070          GOTO 10
0071          END


                FORTRAN IV      STORAGE MAP

                NAME    OFFSET  ATTRIBUTES

                X       000014  REAL*4     PARAMETER VARIABLE
                Y       000016  REAL*4     PARAMETER VARIABLE
                IC      000020  INTEGER*2  PARAMETER VARIABLE
                IHELL   000026  INTEGER*2  VARIABLE
                ISWP    000030  INTEGER*2  VARIABLE
                X1      000032  REAL*4     VARIABLE
                Y1      000036  REAL*4     VARIABLE
                IC1     000042  INTEGER*2  VARIABLE
                W       000044  REAL*4     VARIABLE
                X2      000050  REAL*4     VARIABLE
                Y2      000054  REAL*4     VARIABLE
                IW      000060  INTEGER*2  VARIABLE
                IC2     000062  INTEGER*2  VARIABLE
                ICO     000064  INTEGER*2  VARIABLE
                PLOT    000000  REAL*4     PROCEDURE
                MOD     000000  INTEGER*2  PROCEDURE


                COMMON BLOCK /WINDOW/   LENGTH 000070

                CX      000000  REAL*4     VARIABLE
                CY      000004  REAL*4     VARIABLE
                SIZ     000010  REAL*4     VARIABLE
                WL      000014  REAL*4     VARIABLE
                WR      000020  REAL*4     VARIABLE
                WB      000024  REAL*4     VARIABLE
                WT      000030  REAL*4     VARIABLE
                IA1     000034  INTEGER*2  VARIABLE
                IA2     000036  INTEGER*2  VARIABLE
                IB1     000040  INTEGER*2  VARIABLE
                IB2     000042  INTEGER*2  VARIABLE
                IAC     000044  INTEGER*2  VARIABLE
                IRC     000046  INTEGER*2  VARIABLE
                IR1     000050  INTEGER*2  VARIABLE
                IR2     000052  INTEGER*2  VARIABLE
                IWW     000054  INTEGER*2  VARIABLE
                XP      000056  REAL*4     VARIABLE
                YP      000062  REAL*4     VARIABLE
                ICP     000066  INTEGER*2  VARIABLE
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 14:00:13
CORE=14K, UIC=[203,100]                          ,DRWLMK/-SP=DRWLMK

      C-----------------------------------------------------------------
0001          SUBROUTINE DRWLMK
0002          INTEGER C(10)
0003          COMMON/LMKCOM/IC(10),IX(10),IY(10),IS(10),N
0004          COMMON/WINDOW/CX,CY,SIZE,WL,WR,WB,WT
             *  ,IA1,IA2,IB1,IB2,IAC,IRC,IR1,IR2,IWW
0005          DO 10 J=1,N
0006          X=IX(J)
0007          Y=IY(J)
0008          S=IS(J)
0009          IF(X.GT.WR.OR.X.LT.WL
             *  .OR.Y.GT.WT.OR.Y.LT.WB)GOTO10
0011          CALL SQUARE(X,Y,S)
0012          CALL TEXT(X+S,Y,2,IC(J))
0013    10    CONTINUE
0014          RETURN
0015          END


                    FORTRAN IV      STORAGE MAP

                    NAME    OFFSET  ATTRIBUTES

                    C       000014  INTEGER*2 ARRAY (10)
                    J       000042  INTEGER*2 VARIABLE
                    X       000044  REAL*4    VARIABLE
                    Y       000050  REAL*4    VARIABLE
                    S       000054  REAL*4    VARIABLE
                    SQUARE  000000  REAL*4    PROCEDURE
                    TEXT    000000  REAL*4    PROCEDURE

                    COMMON BLOCK /LMKCOM/   LENGTH 000122

                    IC      000000  INTEGER*2 ARRAY (10)
                    IX      000024  INTEGER*2 ARRAY (10)
                    IY      000050  INTEGER*2 ARRAY (10)
                    IS      000074  INTEGER*2 ARRAY (10)
                    N       000120  INTEGER*2 VARIABLE

                    COMMON BLOCK /WINDOW/   LENGTH 000056

                    CX      000000  REAL*4    VARIABLE
                    CY      000004  REAL*4    VARIABLE
                    SIZE    000010  REAL*4    VARIABLE
                    WL      000014  REAL*4    VARIABLE
                    WR      000020  REAL*4    VARIABLE
                    WB      000024  REAL*4    VARIABLE
                    WT      000030  REAL*4    VARIABLE
                    IA1     000034  INTEGER*2 VARIABLE
                    IA2     000036  INTEGER*2 VARIABLE
                    IB1     000040  INTEGER*2 VARIABLE
                    IB2     000042  INTEGER*2 VARIABLE
                    IAC     000044  INTEGER*2 VARIABLE
                    IRC     000046  INTEGER*2 VARIABLE
                    IR1     000050  INTEGER*2 VARIABLE
                    IR2     000052  INTEGER*2 VARIABLE
                    IWW     000054  INTEGER*2 VARIABLE
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 14:00:31
CORE=14K, UIC=[203,100]                              ,DRWRDL/-SP=DRWRDL

0001          SUBROUTINE DRWRDL (IA1,IA2,IR1,IR2,INC,IXO,IYO,IAO,SCF)
0002          COMMON /WINDOW/ CX,CY,SIZ,WL,WR,WB,WT,IIA1,IIA2,
             *    IB1,IB2,IAC,IRC,IIR1,IIR2,IWW,XP,YP,ICP
0003          IA=IAO-INC
0004          IF=IAO+3600
0005          IAB=IA1+IAO
0006          IAE=IA2+IAO
0007          IF (ICLEAR(IAO).EQ.ICLEAR(IAE)) IA=IA+INC
0009   20     IA=IA+INC
0010          IF (IA.GT.IF) GOTO 200
0012          IF (INAZ(IA,IAB,IAE).EQ.0) GOTO 20
0014          CALL PLOTR (FLOAT(IA),FLOAT(IR1),3,IXO,IYO,SCF)
0015          CALL PLOTR (FLOAT(IA),FLOAT(IR2),2,IXO,IYO,SCF)
0016          GOTO 20
0017   200    RETURN
0018          END


                FORTRAN IV      STORAGE MAP

                NAME     OFFSET  ATTRIBUTES
                IA1      000014  INTEGER*2 PARAMETER VARIABLE
                IA2      000016  INTEGER*2 PARAMETER VARIABLE
                IR1      000020  INTEGER*2 PARAMETER VARIABLE
                IR2      000022  INTEGER*2 PARAMETER VARIABLE
                INC      000024  INTEGER*2 PARAMETER VARIABLE
                IXO      000026  INTEGER*2 PARAMETER VARIABLE
                IYO      000030  INTEGER*2 PARAMETER VARIABLE
                IAO      000032  INTEGER*2 PARAMETER VARIABLE
                SCF      000034  REAL*4    PARAMETER VARIABLE
                IA       000042  INTEGER*2 VARIABLE
                IF       000044  INTEGER*2 VARIABLE
                IAB      000046  INTEGER*2 VARIABLE
                IAE      000050  INTEGER*2 VARIABLE
                ICLEAR   000000  INTEGER*2 PROCEDURE
                INAZ     000000  INTEGER*2 PROCEDURE
                PLOTR    000000  REAL*4    PROCEDURE
                FLOAT    000000  REAL*4    PROCEDURE
                COMMON BLOCK /WINDOW/   LENGTH 000070
                CX       000000  REAL*4    VARIABLE
                CY       000004  REAL*4    VARIABLE
                SIZ      000010  REAL*4    VARIABLE
                WL       000014  REAL*4    VARIABLE
                WR       000020  REAL*4    VARIABLE
                WB       000024  REAL*4    VARIABLE
                WT       000030  REAL*4    VARIABLE
                IIA1     000034  INTEGER*2 VARIABLE
                IIA2     000036  INTEGER*2 VARIABLE
                IB1      000040  INTEGER*2 VARIABLE
                IB2      000042  INTEGER*2 VARIABLE
                IAC      000044  INTEGER*2 VARIABLE
                IRC      000046  INTEGER*2 VARIABLE
                IIR1     000050  INTEGER*2 VARIABLE
                IIR2     000052  INTEGER*2 VARIABLE
                IWW      000054  INTEGER*2 VARIABLE
                XP       000056  REAL*4    VARIABLE
                YP       000062  REAL*4    VARIABLE
                ICP      000066  INTEGER*2 VARIABLE
```

```
FORTRAN IV      STORAGE MAP

NAME    OFFSET  ATTRIBUTES

IA1     000014  INTEGER*2 PARAMETER VARIABLE
IA2     000016  INTEGER*2 PARAMETER VARIABLE
IR1     000020  INTEGER*2 PARAMETER VARIABLE
IR2     000022  INTEGER*2 PARAMETER VARIABLE
INC     000024  INTEGER*2 PARAMETER VARIABLE
IXO     000026  INTEGER*2 PARAMETER VARIABLE
IYO     000030  INTEGER*2 PARAMETER VARIABLE
IAO     000032  INTEGER*2 PARAMETER VARIABLE
SCF     000034  REAL*4    PARAMETER VARIABLE
IR      000036  INTEGER*2 VARIABLE
IMF     000040  INTEGER*2 VARIABLE
ARC     000000  REAL*4    PROCEDURE
```

```
FORTRAN IV      V01C-03C        THU 11-JAN-79 14:03:26
CORE=14K, UIC=[203,100]                          ,DRWRGR/-SP=DRWRGR

0001        SUBROUTINE DRWRGR (IA1,IA2,IR1,IR2,INC,IXO,IYO,IAO,SCF)
0002        IR=-INC
0003        IMF=32767-INC
0004  20    IF (IR.GE.IMF) GOTO 200
0006        IR=IR+INC
0007        IF (IR.LT.IR1) GOTO 20
0009        IF (IR.GT.IR2) GOTO 200
0011        CALL ARC (IA1,IA2,IR,IXO,IYO,IAO,SCF)
0012        GOTO 20
0013  200   RETURN
0014        END
```

EXTRACTION OF CAPPIs FROM LOGGED RADAR DATA

B. Wm. Folliott
J. Ramsden

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EXTRACTION OF CAPPIS FROM LOGGED RADAR DATA — SIMULTANEOUS PRECIPITATION MEASUREMENT

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INTRODUCTION

Recent developments in radar and computer technology have allowed recording of vast quantities of weather radar data onto magnetic tape. These data can later be retrieved for post facto analysis, but this has generally involved only short intervals of the data in time and space.

During the 1978 summer operations of the Alberta Hail Project, data from entire days were processed routinely. These achievements are based on the ability of weather radars to provide an estimate of precipitation rate over many small areas. Maps and tables of accumulated rainfall for the entire project area were generated for each day and were available the following morning.

The original data set provides a three-dimensional picture of the atmosphere. A subset of these data, which is representative of a cross section through the atmosphere at a constant altitude, is used for the accumulation of rainfall. These data subsets are referred to as CAPPIs (Constant Altitude Plan Position Indicators).

The usefulness of precipitation measurement using weather radars has been recognized by many. One group, the Flow Forecasting Branch of Alberta Environment, is concerned with river flooding. Information about the amount of rainfall that has fallen on a river basin is useful in forecasting river flow if it can be obtained close in time to the real event.

THE RADAR AND DATA LOGGING SYSTEM

RADAR AS A REMOTE SENSOR

Weather radar data can be used to estimate the rainfall rate at many points in space. A radar transmits from an antenna a pulse of microwave radiation; when this pulse is scattered by precipitation, some of the energy is detected by the antenna. The detected radar signal can be recorded on magnetic tape for later retrieval. The power of the back-scattered radiation is a measure of the rainfall intensity (Battan, 1973). From the radar data, the reflectivity factor is obtained and can be related to the precipitation rate by an expression of the form:

$$Z = aR^b$$

where Z is the reflectivity and R is the rainfall rate in mm/hr.

Marshall and Palmer (1948), after measuring the distribution of raindrops with size, found the Z-R relationship of

$$Z = 200R^{1.6}$$

to be representative for most rains. This provides the basis of the accumulation procedure: for each point of data, the reflectivity provides a measure of the rainfall rate which can be integrated over time to obtain a rainfall amount.

Because of inherent errors in the radar estimate of precipitation, both over-estimates and under-estimates of precipitation are possible. (Cain and Smith, 1976)

THE DATA

The data used in the rainfall accumulation process are collected by a 10-cm radar located at Penhold. Surveillance is maintained over an area of approximately 160 km radius.

The radar data are recorded in a ray by ray format. A ray consists of the time, azimuth, and elevation of the antenna position and 147 data values. These data of reflectivity are at equally spaced range intervals from the radar. Each value is obtained by averaging over both range intervals (1.05 km) and azimuth intervals (about 1 degree). Although each value is often thought of as an instantaneous value at a point, it is actually a spatial average of a volume for a short period of time.

As the radar rotates through 360 degrees of azimuth, one ray of data is recorded for each degree. This forms a polar coordinate grid of some 50,000 points and covers an area of about 76,000 km^2. A display of this data is called a plan position indicator (PPI).

As the antenna rotates, it also elevates through 1 degree for each rotation in azimuth. After elevating from 0 to 8 (or 20) degrees the antenna returns to 0 degrees elevation. This cycle then repeats.

An 8-degree cycle takes 1.5 min to complete; the 20 degree cycle takes 3 min. Each cycle gives a three-dimensional picture of the atmosphere.

Given the range and elevation, the height of echoes above mean sea level can be determined; the height increases with both range and elevation. Each ray is on a slant, that is, data close to the radar are at a lower altitude than data farther from the radar.

Extraneous radar echoes, known as ground clutter, sometimes appear at low elevations close to the radar. At higher elevations, ground clutter does not appear.

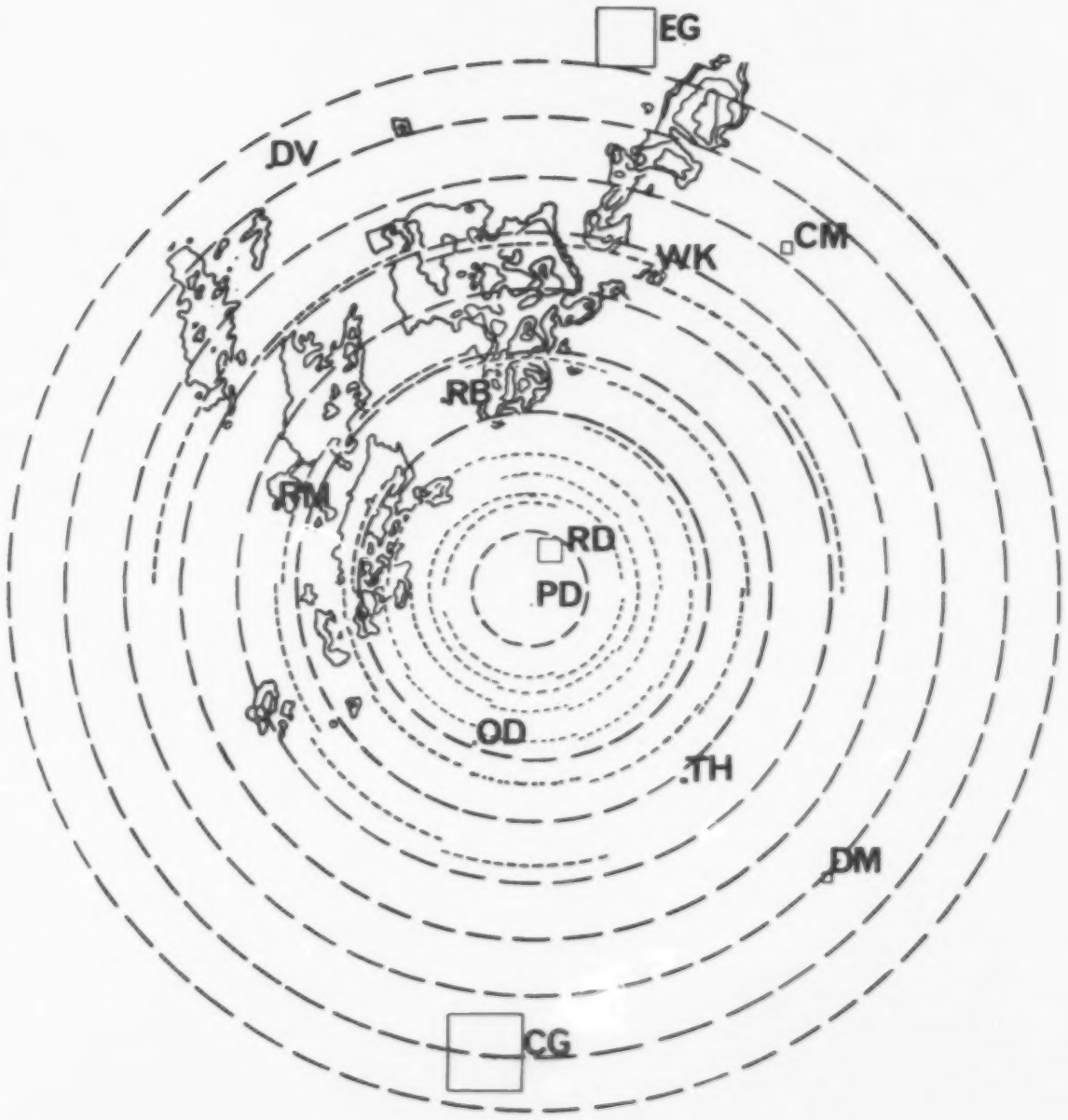

FIGURE 1. Contoured Display of CAPPI Data. The short dashes indicate the start of each ray segment. Long dash range rings are at 16 km (10 mile) intervals.

CAPPIS

For precipitation measurements, data from a PPI are not desirable because of slant range and ground clutter. However, from the three-dimensional data a subset can be used which is representative of a constant altitude over the entire area. This is called a Constant Altitude PPI (CAPPI). During an antenna cycle, data from lower elevations are used for distances far from the radar; as the antenna elevates, data closer to the radar are used. From each ray of data, a segment of the ray is used, representative of the height of the CAPPI. As the segments are selected they form a spiral into the center, producing a display which looks like a cross section of a nautilus. Figure 1 shows a set of CAPPI data that has been contoured. The short dashes indicate the start of each ray segment. The contours enclose radar echoes.

CAPPI data reduce the problems of slant range PPI's. For example, data close to the radar are above ground clutter. Since the radar does not monitor directly overhead, a hole appears in the middle of the CAPPI.

Some care is required in interpreting CAPPI data. The problem of slant range has been reduced but not eliminated. Figure 2 shows that each ray segment is still on a

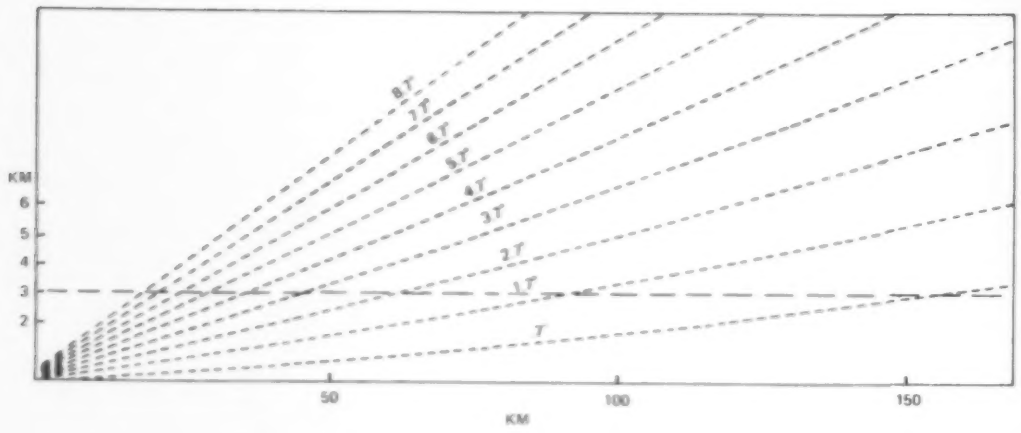

FIGURE 2. Height Plotted Against Range. The ray segments (solid lines) form a ray from a CAPPI with an altitude of 3 km. The dashed lines represent rays from PPI's of different elevations.

slant range; the start of each ray segment (near the radar) is at a lower height than the far end. However, a ray segment close to the radar will represent the same height as a ray segment far from the radar, and the problem of slant range does not manifest itself as dramatically as would a single ray of data from a slant range PPI.

In a ray of CAPPI there are discontinuities between the end of one ray segment and the start of the next, since the ray segments are selected at different elevations. For this reason contours between ray segments sometimes do not match smoothly.

The segments form a continuous set of data in azimuth, except at the start of the CAPPI. During the first rotation of a cycle the outer part of the spiral extends to the full range of the radar, so there is a 1-degree jump at the start.

It is interesting to note that although these discontinuities are in each CAPPI, maps of accumulated rainfall produced by integrating over time do not have apparent discontinuities.

PRECIPITATION MEASUREMENT

The data from CAPPIs can be used in deriving the total precipitation over a period of time. Using the Z-R relationship the precipitation rate can be evaluated. The time between CAPPIs is known so the rainfall amount between CAPPIs can be calculated and added to the previous total. To maintain full spatial resolution, this involves accounting for some 50,000 totals. When the data accumulation is complete, maps can be generated.

The approach taken to determine the rainfall amount over an area (for instance a township or river basin) is only slightly different. For each CAPPI an average rainfall rate is computed for each area of interest. These rates are saved and later processed to determine the total rainfall amount in each area.

Originally the areas of interest were river basins. These were drawn on a map and a polar coordinate grid was overlaid. For each ray of data it was determined which grid points lay in which areas. Use of a digitizer should simplify this procedure in the future.

PROGRAMMING IMPLEMENTATION

CAPPIs are extracted and accumulated rainfall maps are produced primarily by three programs. One program extracts the CAPPI, reading from the input tape of logged radar data and writing the CAPPI to the output tape. As the data are extracted, they are passed to the next program which converts the radar data to rainfall rate. The summary maps and maximum reflectivity map are maintained. The data are then made available to a third program which updates the average rainfall rate for each basin and the rainfall amount at each point in the CAPPI.

The programs are modular in nature. Normally all three programs run concurrently, but an operator may run only the first or first two programs, if desired. The structure of the programs showing the major inputs and outputs is diagrammed in figure 3.

EXTRACTION

The logged radar data are processed in a sequential manner. The tape is first positioned automatically to 270 degrees azimuth in the PPI that contains 0.5 degree elevation. This is done for the following reason. On the first scan of each antenna cycle the antenna rotates in azimuth from 0 to 360 degrees (from north clockwise back to north), at the same time elevating from 0 to 1 degree. Thus when the antenna is pointing toward the southwest between 200 degrees azimuth and 270 degrees azimuth, its elevation is about 0.6 to 0.7 degree. This is low enough to receive echoes from the Rocky Mountains, which have some peaks over 10,000 feet above sea level. Since one of the reasons for extracting CAPPI data is to obtain data free of ground echoes, these Rocky Mountain echoes must not be extracted as part of the CAPPI data. This is ensured by extracting no data until after the antenna has elevated above 0.75 degree, which is equivalent to waiting until the antenna has rotated past 270 degrees azimuth on the first (0 to 1 degree elevation) scan.

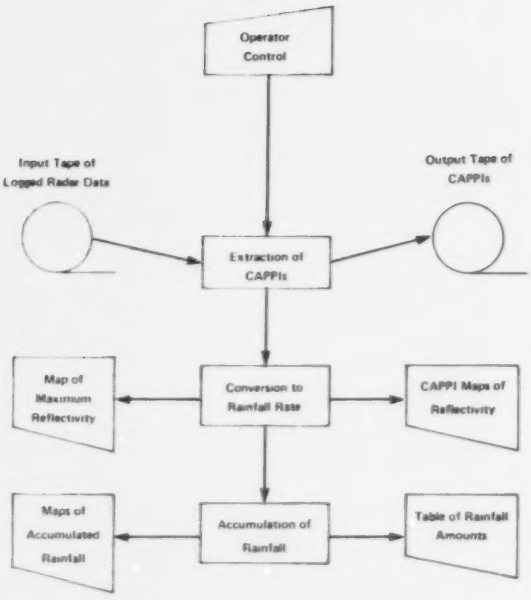

FIGURE 3. Structure of computer programs showing major inputs and outputs.

Since the antenna program of the radar is fixed, it is possible to fix the beginning and ending range values for each ray segment. Each time the elevation changes the end points of the ray segments are changed. The elevation increases in steps of 0.1 degree after approximately every 36 rays of data.

All CAPPIs for a given altitude are identical, in that they all start at 270 degrees azimuth and corresponding ray segments at a given azimuth have the same beginning and ending range values. For this reason, any point in one CAPPI is comparable to the same point in any other CAPPI.

Since a ray of radar data may not lie exactly on a whole degree, the closest ray to each degree of azimuth is chosen and the ray segment is then extracted from this ray. This method is fast as no processing of the data is done.

From time to time there are gaps in the logged radar data and occasionally the radar program deviates from the one described. A check is made periodically to ensure that the data extracted are within 2 degrees of the expected azimuth and are also close to the expected elevation. If a departure is detected then the CAPPI is deleted from the output tape and appropriate action is taken by the other programs not to process the data of the incomplete CAPPI. Such deletions are few and often are the result of an interruption in the logging of radar data.

REFLECTIVITY MAPS

The second program converts the radar data to rainfall rate. At the same time a map of maximum reflectivity is updated and once an hour a CAPPI map of reflectivity for that cycle is generated. Examples of these are shown in figures 4 and 5. The maps are printed at 16 mi/in scale. The reflectivity maps form a summary for the day. The maximum reflectivity map is used by the Alberta Hail Project at Penhold to determine where the telephone survey should be directed: residents in areas underlying regions of high reflectivity are contacted.

ACCUMULATION

For the accumulation, full spatial resolution is maintained. In order to do this, two disk files, each containing a full resolution CAPPI, are maintained. Data are read from one file, updated, and written to the other file. When the CAPPI is finished the files are switched. These data are used to generate a large scale map (8 mi/in) which can be conveniently overlaid on project area maps. Excellent information is thus provided about the precipitation patterns. An example is shown in figure 6. Table 1 lists rainfall amounts in millimetres, resolved in an hourly and river subbasin format.

OPERATION

Use of the programs is simple for a person unfamiliar with programming. After loading the first tape of logged radar data and an output tape for the extracted CAPPIs, the process is initiated by a simple command. The operator is prompted for pertinent information and the process begins. Periodic changing of input and output tapes is all that is required.

At the completion of a day's run, another set of commands will save the maps and tables on tape. Printer output can be collected and filed.

From May through September, during the operations of the Alberta Hail Project, radar data were recorded. Typically this covers periods when storm activity is greatest. In 1978 the tapes for a day were sent in the evening by bus express to Edmonton. They were picked up by a night shift, and processing started shortly after midnight and continued until the next morning.

Each morning Alberta Environment phoned in to the computer, automatically initiating a procedure to print messages and, if they wished, the maps and tables for the previous day.

PRECIPITATION MEASUREMENT IN REAL TIME

During September 1978, a study was made to determine the feasibility of measuring the accumulation of rainfall in real time. As a result of work done for the real-time display program (Humphries et al, 1978), data from a select PPI can be written to disk as the data are being logged onto magnetic tape. These data can then be accessed and used by the accumulation programs. For a 3-min radar cycle, the programs were able to complete the accumulation in time to request data from the next cycle. This provides

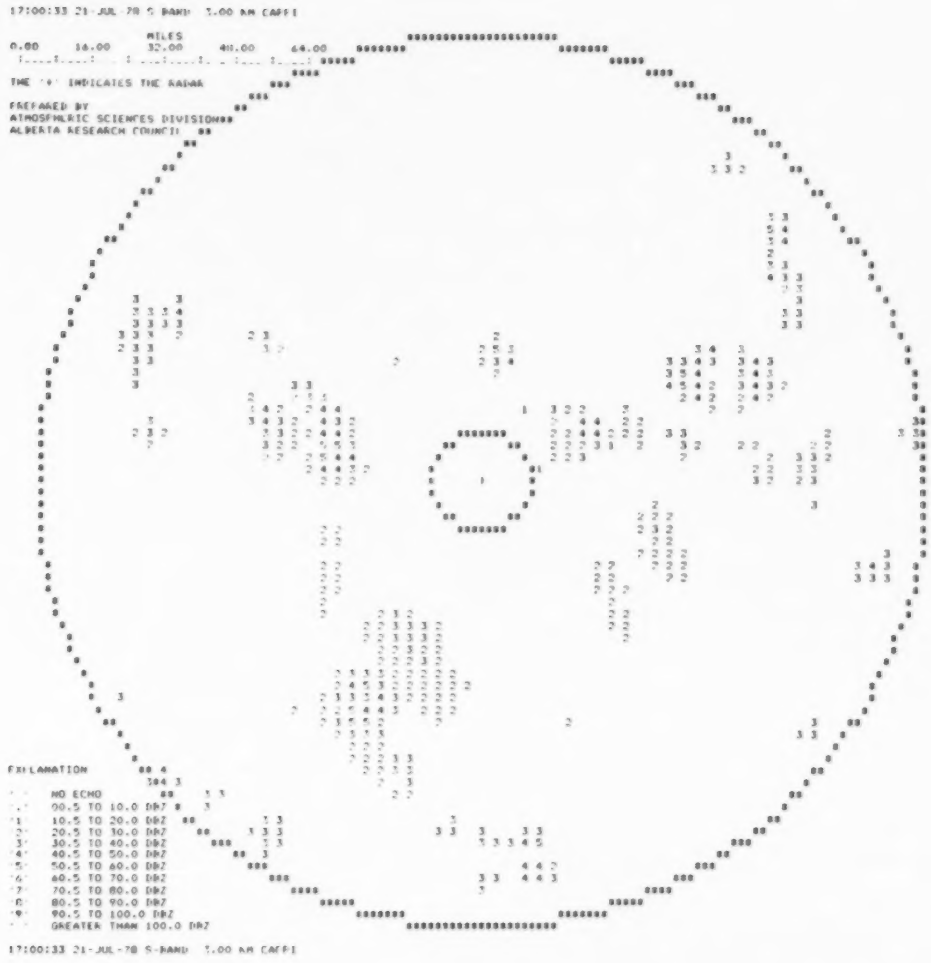

FIGURE 4. Sample CAPPI Map of Reflectivity. This printer map is for the CAPPI of the radar cycle that starts at 17:00:33. The radar is at Penhold and the radar echoes are shown as numbers which are explained by the legend at the side. Storms for this day moved in a south east direction.

current information. Although the data are from a PPI rather than a CAPPI, useful real-time information about spatial distributions of rainfall is still obtained.

This program still requires the supervision of a programmer, but integration of the program into the daily operation was completed in spring 1979. Unfortunately, real-time accumulation cannot be done if the real-time display is active.

SUMMARY

The ability to process large quantities of data routinely, and to provide results that are close in time to the real events has been accomplished. This has required software with special capacities. Ease of operation with a minimum of programmer supervision, smooth recovery from system or human interruption, and fast execution have all been given special consideration.

The extraction of CAPPI data and accumulation of rainfall has produced information that is quickly accessible and useful to those that have no special knowledge of radar meteorology or computers. A data base of CAPPIs is produced which is useful for other purposes.

The information generated is outstanding. In the past, few have been treated to the high resolution presentation of precipitation patterns covering such a large area and so close in time to the real event. The maps provide a wealth of visual information that is further condensed to numerical form in the table.

Interpretation and use of this information will increase now that the software to handle aggressively such vast amounts of data has been developed.

The Flow Forecasting Branch of Alberta Environment has been enthusiastic in considering the data, despite limited

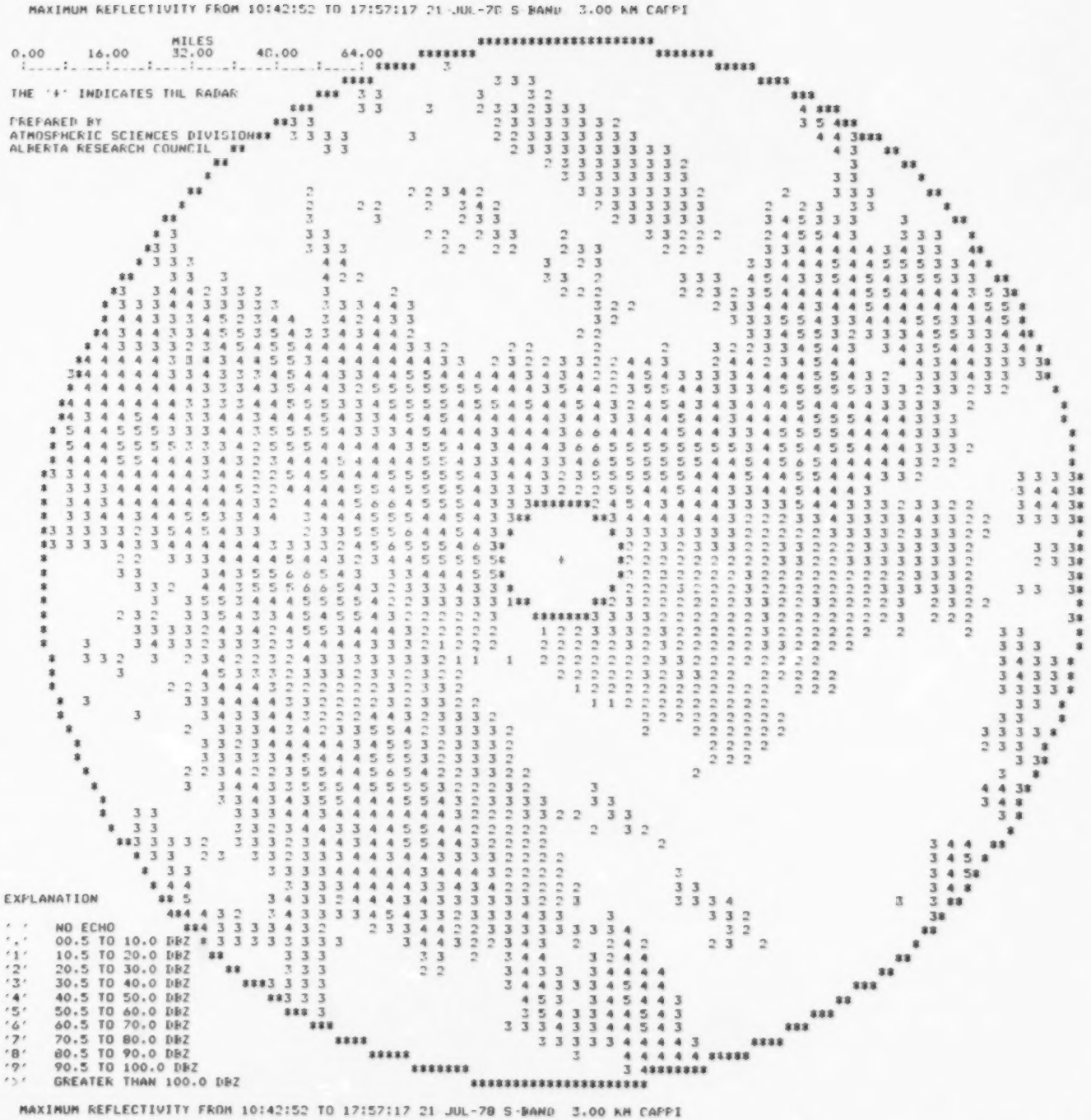
MAXIMUM REFLECTIVITY FROM 10:42:52 TO 17:57:17 21 JUL-78 S BAND 3.00 KM CAPPI
MILES
0.00
16.00
32.00
40.00
64.00
THE '+' INDICATES THE RADAR
PREPARED BY
ATMOSPHERIC SCIENCES DIVISION
ALBERTA RESEARCH COUNCIL
EXPLANATION
' ' NO ECHO
'.' 00.5 TO 10.0 DBZ
'1' 10.5 TO 20.0 DBZ
'2' 20.5 TO 30.0 DBZ
'3' 30.5 TO 40.0 DBZ
'4' 40.5 TO 50.0 DBZ
'5' 50.5 TO 60.0 DBZ
'6' 60.5 TO 70.0 DBZ
'7' 70.5 TO 80.0 DBZ
'8' 80.5 TO 90.0 DBZ
'9' 90.5 TO 100.0 DBZ
'>' GREATER THAN 100.0 DBZ
MAXIMUM REFLECTIVITY FROM 10:42:52 TO 17:57:17 21 JUL-78 S-BAND 3.00 KM CAPPI

FIGURE 5. Sample Map of Maximum Reflectivity. This map was generated using each CAPPI in the period 10:42 to 17:57. The map indicates where there was echo and the maximum echo at that point. There is a legend at the side.

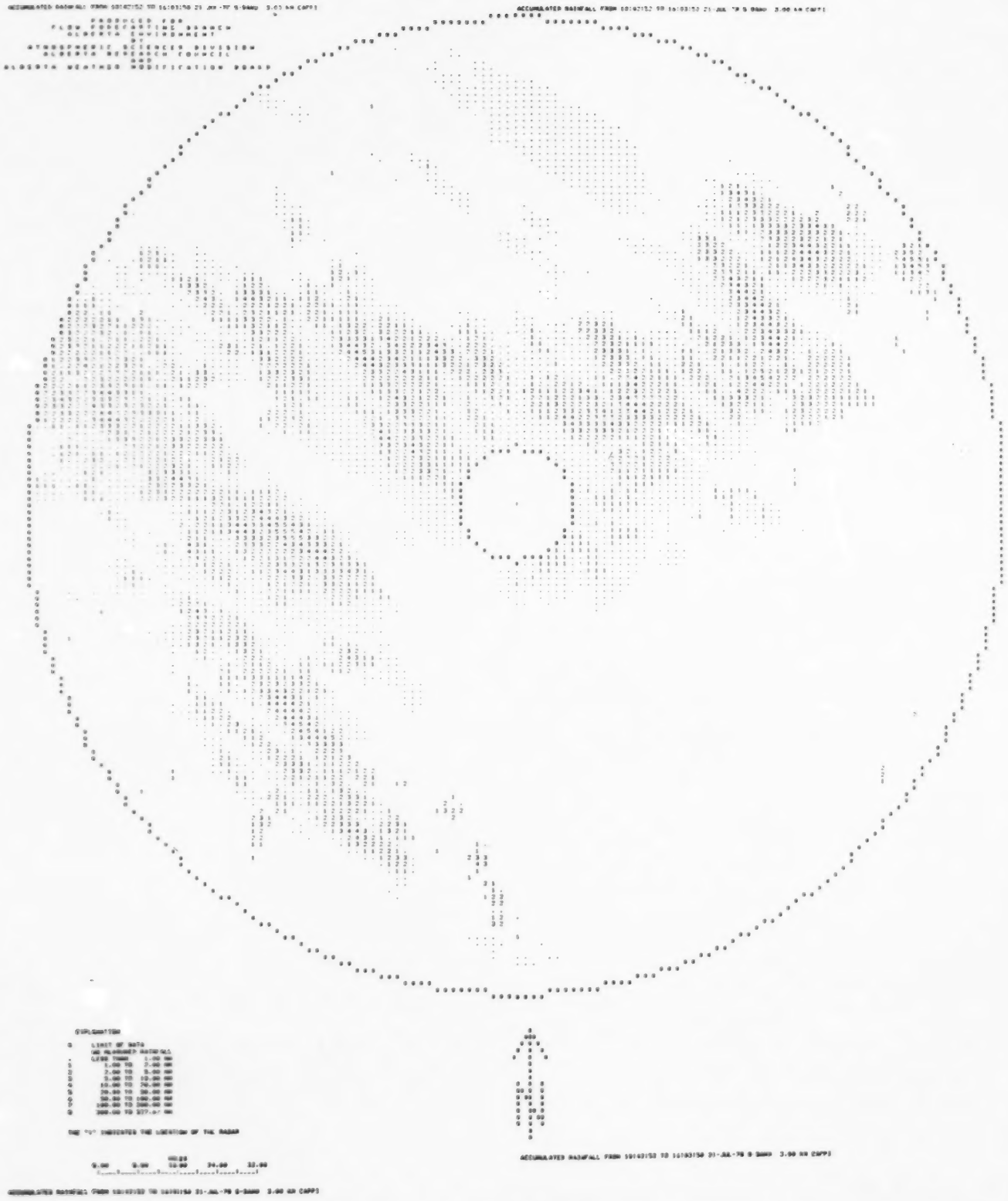

FIGURE 6. Sample Map of Accumulated Rainfall. This map for the period 10:42 to 16:03 shows the accumulated rainfall. Printed at a scale of 8 mi/in., it can be conveniently overlaid on project maps. Storm tracks are easily picked out.

TABLE 1
Sample Table of Accumulated Rainfall.

21-JUL-79 S-BAND 3.00 KM CAPPI HOURLY ACCUMULATIONS BY BASINS (MM)

FROM:		10:43	11:01	12:00	13:02	14:01	15:01	16:04	17:01
TO:		11:01	12:00	13:02	14:01	15:01	16:04	17:01	17:54
INTERVAL:		00:18	01:00	01:01	01:00	01:00	01:03	00:57	00:54
ACCUMULATED:		00:18	01:00	01:01	01:00	01:00	00:33	00:57	00:54
BASIN	AREA								
SUB-	2								
BASIN	(KM)								
BOW RIVER BASIN									
WA01	335.79	0.00	0.00	0.00	0.06	0.05	0.20	0.04	0.00
JP01	527.20	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.08
BASIN MEAN	862.98	0.00	0.00	0.00	0.02	0.03	0.08	0.03	0.05
NORTH SASKATCHEWAN RIVER BASIN									
CW01	1020.35	0.00	0.00	0.00	0.01	0.06	0.01	0.00	0.00
CW02	1926.98	0.00	0.00	0.03	0.25	0.94	0.72	0.16	0.02
BASIN MEAN	2947.32	0.00	0.00	0.02	0.17	0.63	0.47	0.10	0.01
RED DEER RIVER BASIN									
RD01	743.50	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
RD02	757.55	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.01
BT01	338.21	0.00	0.00	0.00	0.02	0.38	0.01	0.01	0.00
JA01	824.18	0.00	0.00	0.00	0.06	0.64	0.76	0.14	0.00
BB01	289.85	0.00	0.00	0.00	0.00	0.04	0.03	0.21	0.00
RA01	588.78	0.00	0.00	0.00	0.07	0.25	1.18	0.08	0.32
ME01	1875.22	0.01	0.04	0.00	0.70	1.09	0.01	0.54	0.37
LR01	501.44	0.00	0.00	0.00	0.03	0.66	1.53	0.66	0.01
LR02	2023.14	0.00	0.00	0.00	0.01	0.01	0.02	1.20	0.38
BASIN MEAN	7941.87	0.00	0.01	0.00	0.19	0.41	0.27	0.50	0.21
BATTLE RIVER BASIN									
BA01	1874.65	0.00	0.00	0.00	0.03	0.20	0.05	0.09	0.52
FF01	568.84	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00
BA02	4705.12	0.00	0.00	0.00	0.01	0.50	0.47	0.08	0.11
??01	469.88	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
BASIN MEAN	7618.49	0.00	0.00	0.00	0.01	0.36	0.30	0.07	0.20
RAIN GAUGE STATIONS									
GH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00
EB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

During the 1 hr and 3 min from 15:01 to 16:04, only 33 min were used in the accumulation, as there was a gap in the data. The James River (JA01) subbasin got 0.76 mm of rain which contributed to the Red Deer River Basin average of 0.27 mm.

results of the initial implementation. A raingauge is able to measure the rainfall at a point. A radar is able to describe the rainfall over many small areas. Usually a raingauge network is not sufficiently dense to obtain a good measure of the rainfall amount in a river basin. The areal radar measurements provide additional information for estimating precipitation amount. The maps and tables augment traditional data and can influence the data now used in stream flow model input.

ACKNOWLEDGMENTS

John Ramsden designed and implemented the software. Aldo Bellon of McGill University was consulted on similar work. This work was supported by the Alberta Weather Modification Board.

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HAILPAD DATA COLLECTION AND REDUCTION

L. Wojtiw

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HAILPAD DATA COLLECTION AND REDUCTION

L. Wojtiw

OBSERVATIONS

The primary source of objective hailfall data is the hailpad — a styrofoam pad measuring 30.5 cm x 30.5 cm x 2.5 cm. Hailpads were set out in three networks during the summer months in central Alberta from 1974 to 1978.

The three networks and their locations are shown in figures 1 and 2. These are:

1) a precipitation network of about 500[1] stations over an area of 33,000 km^2

2) a dense network of about 160[2] stations over an area of 932 km^2 (embedded within the large precipitation network in the Rimbey district of Alberta); and

3) two micro-dense networks of 26 and 16 stations in an area of 0.6 km^2 (embedded in the dense network).

The hail size distribution and the areal concentration of the hailstones for the duration of a hailstorm can be obtained by analyzing the hailpads. However, the pads do not give time-resolved information about the hailfall, which is important for relating cloud seeding events to hailfall on the ground.

All stations (volunteer observers) in the first two networks were supplied with four styrofoam pads, a pad holder[3] mounted on a supporting stand[4] (Fig. 3), a raingauge[5], and appropriate forms to report the occurrence of hailfall and the total amount of daily precipitation.

Each station operator was asked to change the pad immediately after the hailstorm or once a week, or if the pad became damaged in any way. Field tests in 1975 showed that the pad begins to deteriorate after 10 days in sunlight. Beyond ten days, the deterioration is rapid and the sizes of hail dents made thereafter are unreliable.

[1] The number of stations in the precipitation network varied from year to year, ranging from 487 stations in 1977 to 516 in 1978.

[2] The number of stations in the dense network varied from year to year, from 121 stations in 1975 to 162 in 1976.

[3] A 30.5 cm x 30.5 cm x 2.5 cm plywood board with two narrow metal slits on two of the sides of the board to hold the hailpad in place.

[4] A 5.1 cm x 10.2 cm x 1.8 cm two-by-four, or fence pole is available.

[5] A plastic wedge type manufactured by Edwards Manufacturing Co., Minnesota, U.S.A. called Tru-Check.

When they arrive from the manufacturer, the styrofoam pads are quite coarse. In order that the roughness is not mistaken for small hail dents, a pad sander (Fig. 4) was developed in 1975 at the Alberta Research Council. The dented pads, returned from the field, were then inked with a print roller to provide contrast between the uninked hail dents and the inked undented background styrofoam. Figure 5 shows an example of an uninked and an inked pad. A quantitative measure of the number of hailstones in various size categories can be obtained from the hail dents. These measurements are used to calculate the impact energy per unit area (subsequently referred to as the *impact energy density*).

ANALYSIS OF THE HAILPADS

The analysis of the pads for hail size distribution and concentration was carried out by hand. This involves the use of a transparent overlay (Fig. 6a for 1974 to 1977 hailpads) with imprinted circles of diameters 0.25 cm to 2.54 cm at 0.25 cm intervals, and 2.54 cm to 5.08 cm at 0.63 cm intervals. The dent was estimated to the nearest 0.13 cm and placed in the appropriate size category. For example, if a dent was larger than 0.25 cm but smaller than 0.38 cm, it would be placed in the 0.25 cm category. This procedure gives rise to an underestimate of the sizes, and as a result, an underestimate of the calculated impact energy density. The magnitude of the error in the impact energy density increases as D^4 where D is the hailstone diameter. The maximum error in the impact energy density occurs if all the size categories are underestimated by one size category. In this case, the error in the impact energy density is 80.2 percent for the 0.25 cm category and decreases proportionally as D^4 to an error of 17.7 percent in the 2.54 cm category. For the 29 July 1974 hailswath, the maximum error in the impact energy density, assuming that all the dent size categories are underestimated by one size catgegory, is 36.9 percent. For 1978 hailpads the transparent overlay in figure 6b was used, with imprinted circles of 0.1 cm diameters in 0.1 cm intervals, up to 4.0 cm. The error arising from using this overlay is slightly less than using the overlay in figure 6a, but is of the same magnitude.

The number of dents of each size category was recorded for each hailpad. In order to convert from dent sizes to hail sizes, three calibration curves were used and are shown in figure 7. Curve 1 represents the aluminum foil-covered hailpads used in 1974 (Strong and Lozowski, 1977), curve 2 shows the uncovered hailpads used in the project from 1975 to 1977 (Strong and Lozowski, 1977), and curve 3 shows the SI hailpads[6] used in 1978.

[6] Commercial name for type of styrofoam.

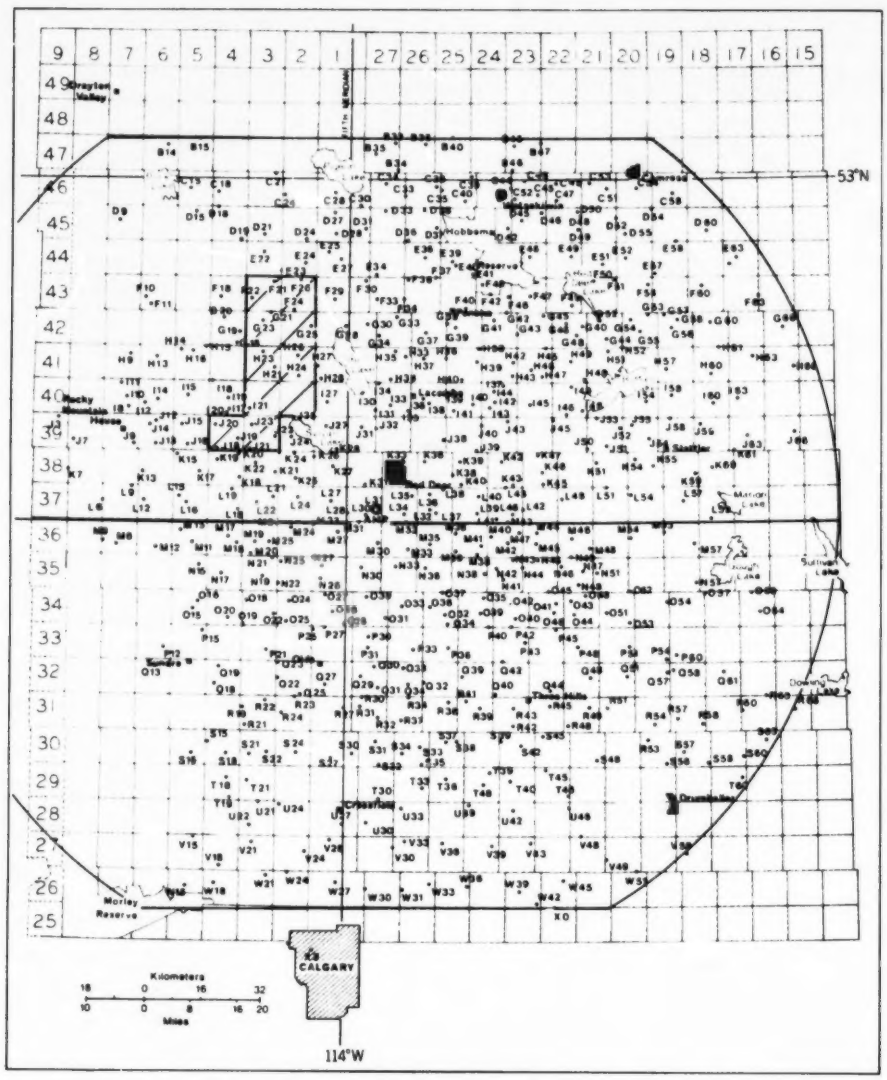

FIGURE 1. Map showing networks in the Alberta Hail Project.

CALCULATION OF IMPACT ENERGY DENSITY

The kinetic energy of a hailstone upon impact (impact energy), assuming no horizontal wind component, can be calculated from the hailpad data using the following formulas (Strong, 1974). For a spherical hailstone of mass M, diameter D, density ρ, and falling with terminal velocity V_T through air of density ρ_a, the equation of motion can be solved to yield:

$$V_T = \left(\frac{4\rho g D}{3\rho_a C_D}\right)^{1/2} \quad (1)$$

The following parameters were found to be most appropriate for typical Alberta conditions (at a pressure of 890 mb and a temperature of 22°C) (Strong, 1974): drag coefficient $C_D = 0.60$, hailstone density $\rho = 0.89$ g cm^{-3}, surface air density $\rho_a = 1.05 \times 10^{-3}$ gm cm^{-3} and g = 981.3 cm s^{-2}. Using these values, Equation becomes:

$$V_T = 13.6\, D^{1/2} \quad (2)$$

where V_T is in meters per second and D in centimeters.

This relation was confirmed by Lozowski and Beattie (1975), who used highspeed photography to measure the terminal velocity of hailstones up to 1 cm in diameter for several 1974 Alberta hailstorms. They found that the curve $V_T = 13.3\, D^{1/2}$ was a reasonable fit to their measurements.

The kinetic energy for a single stone on impact (Wojtiw, 1977) is therefore:

$$I_E = \frac{\pi \rho^2 g}{9 \rho_a C_D} D^4 \quad (3)$$

Substituting the typical values for the various parameters into Equation 3 yields:

$$I_E = 4.307 \times 10^{-2} D^4 \quad (4)$$

where I_E is in Joules and D in centimeters.

This equation gives the kinetic energy of a single hailstone. In order to calculate the total kinetic energy for the stones on the hailpad, for each of the size categories, an impact energy is determined for each category and these values are then summed. Equation 4 then describes the impact energy density on the hailpad as:

$$I_{ET} = 4.636 \times 10^{-1} \sum_{1=1}^{P} A_1 D_1^4 \, (Jm^{-2}) \quad (5)$$

where D_1 is the diameter in centimeters, and A_1 is the number of hailstones on the hailpad in the i^{th} size category (for i = 1, P where P is the number of size categories).

Equations for a hailstone falling in a horizontal wind are given in Wojtiw (1977) but are not presented here, since these have not yet been incorporated into the calculation of impact energy density from the hailpads. Hence, the impact energy density values used in the following sections will be values calculated assuming no horizontal wind component. Few hailpads have wind information accompanying the hailfall information. Wind speed, however, is an important quantity. Strong winds can cause 30 percent more hail damage to crops than light to moderate winds (Wojtiw and Renick, 1973). Morgan and Towery (1975) suggests that wind contributes to even greater crop damage, but the magnitude of the effect is not given. Hence, this quantity should not be ignored in the evaluation of hail suppression. Using a hailcube, (five hailpads joined to form a cube, minus the bottom hailpad), Morgan has been able to estimate the horizontal wind component (Vento and Morgan, 1976). These cubical units have been used only in the micro-dense networks for two years (1977 and 1978), but should be considered in setting up future networks.

SUMMARY OF HAILPAD OBSERVATIONS

A daily summary of the hailpads observations collected in the precipitation and dense networks during the last five years (1974 to 1978) is given in the appendix. For each day listed, the number of pads collected and the total number of impact counted are supplied. Also given is the average impact energy density per pad (in J m^{-2}) and whether the day was a seed or no-seed day in the north area. An overall summary of the information found in the appendix and given in table 1 shows that 3004 pads were collected on 215 different days during the five summers. The largest number of days with pad data occurred in 1977 (55), the smallest in 1974 (32), while the five year average was 43 days. The number of days with pad data was smaller than that reported by the hailcard system due to the differences in density of the collecting systems. In 1978, the largest number of pads was collected, while the smallest was in 1974. The number of impacts counted and the average number of impacts per pad were greatest in 1978, and these values were much larger than in any of the other years. With an increase in the number of impacts per pad, the average impact energy density may also increase and did in 1978. The lowest average impact energy density was observed in 1977 data with a large number of impacts per pad, implying there were many small stones that year which contributed very little to the overall average impact energy density.

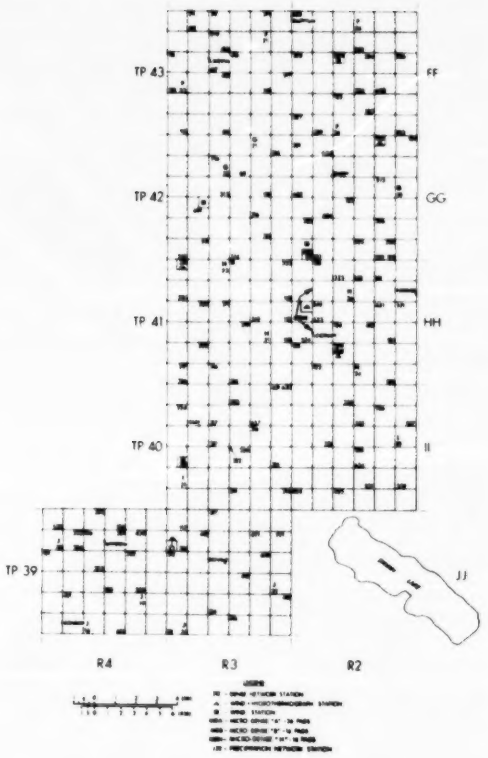

FIGURE 2. Diagram showing locations of hailpad stations in the dense network. (Stations are located in the quarter section where the printed numbers appear.)

CONCLUSIONS

Of the four different types of materials used for hailpads in the project area during the last five years, the SI material (used in 1978) seems to be the easiest to handle from the point of view of reduction and analysis. The hand analysis is cumbersome and time consuming, however, the graphic-computer technology has improved in the last few years and a technique for rapid analysis of this kind of data should become available in the near future.

The physical equations and the parameters used to calculate the impact energy density of hailstones have been reasonably defined, the only exception being the drag coefficient. Strong (1974) theoretically examined this parameter and his average value was used in this study.

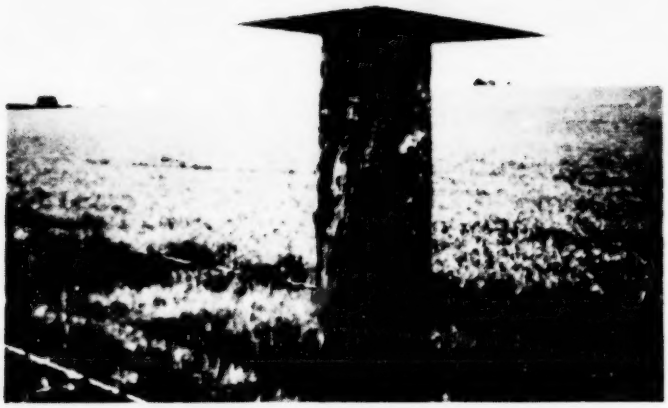

FIGURE 3. Hailpad stand.

FIGURE 4. Pad sander used to eliminate coarseness in the styrofoam.

FIGURE 5. An uninked hailpad, and the same kind of pad after inking, below.

Recent field work from NHRE[9] suggest that the value used in Alberta may be low, and thus a field study of the variation of this parameter is proposed as a research topic.

The hailpads record the hailfall from the time the volunteer observer sets them out to the time they are removed. In most cases, this is the total duration of the hailstorm. To match seeding events and radar measurements to the hailfall it is essential to have time-resolved hailfall measurements. This is an area where future research should be devoted to develop instruments to obtain these ground measurements.

[9] NHRE — National Hail Research Experiment located in the U.S.A. at Boulder, Colorado

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Strong, G.S. (1974): The objective measurement of Alberta hailfall; M.Sc. thesis, Meteorology Division, Dept. of Geography, University of Alberta, Edmonton, Alberta, 182 p.

FIGURE 6. Hailpad overlays used in data analysis.

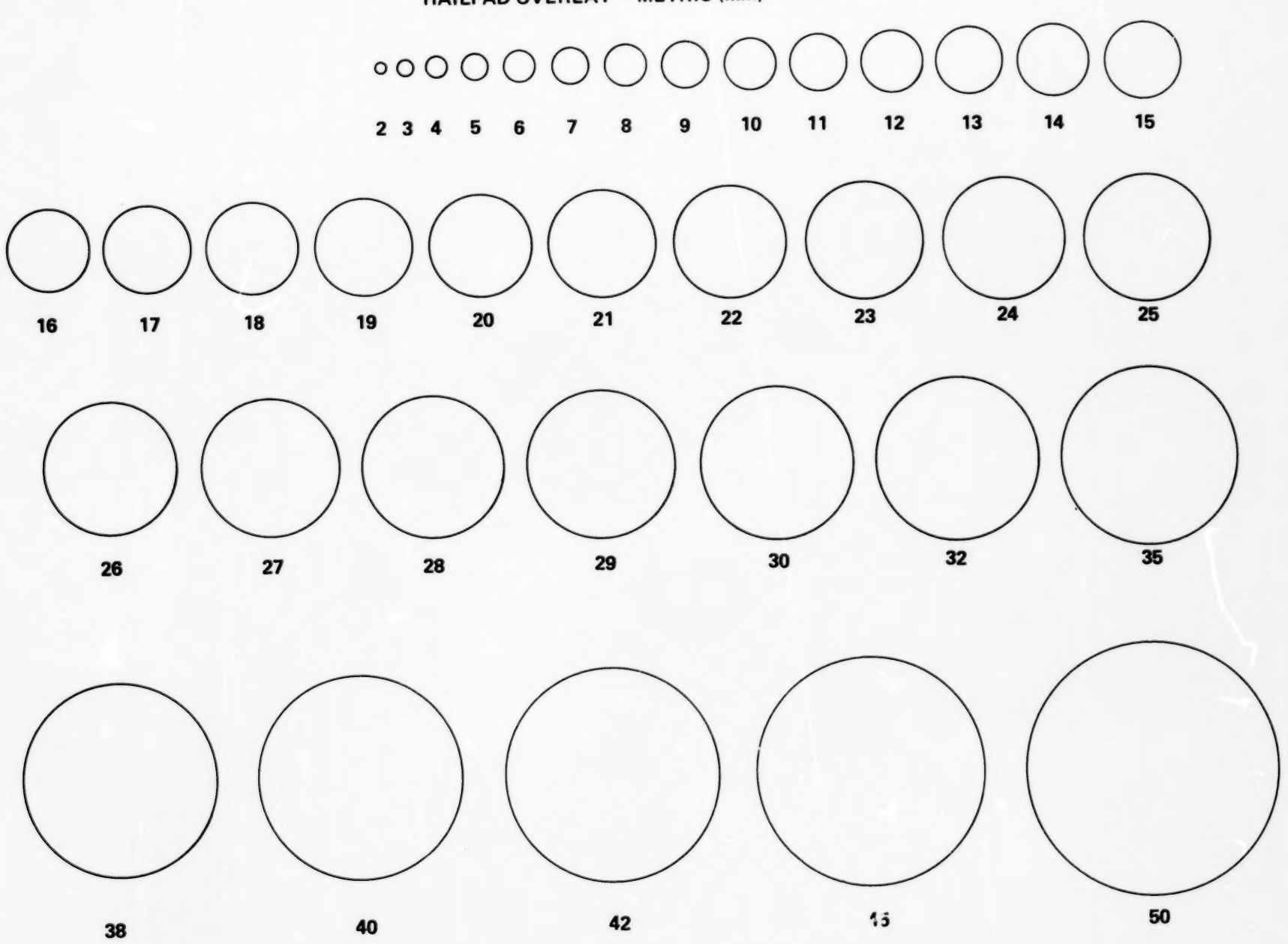

FIGURE 6. (continued)

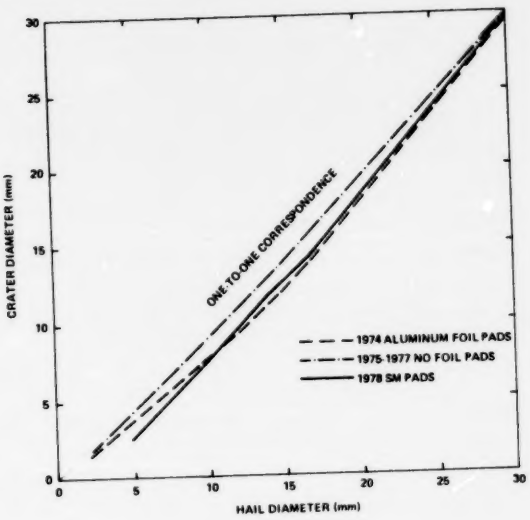

FIGURE 7. Calibration curves used in converting from hail dent to hail diameter.

TABLE 1
SUMMARY OF HAILPAD OBSERVATIONS FOR 1974 - 1978 IN THE PROJECT AREA.

Year	Days With Pad Data	Number of Pads Collected	Number of Impacts Counted	Average Number of Impacts Per Pad	Average I_E Density Per Pad ($J\ m^{-2}$)
1974	32	457	106,122	232	57.9
1975	51	706	191,598	271	73.9
1976	33	546	142,482	261	69.8
1977	44	501	146,034	291	34.6
1978	55	794	366,671	462	78.4
Five Year Total	215	3,004	952,907		
Five Year Average	43	601	190,581	317	65.4

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Wojtiw, L. (1977): An initial assessment of the representativeness and accuracy of Alberta hailpad data; Unpublished M.Sc. thesis, Meteorology Division, Department of Geography, University of Alberta, Edmonton, Alberta, 215 p.

APPENDIX

TABLE 2
Summary of 1974 Hailpad Observations in the Precipitation and Dense Networks

DATE	No. of Impacts Counted		No. of Pads Collected		Avg. No. Impacts Per Pad		Avg. I_E Per Pad ($J\ m^{-2}$)		Status of Day S = Seeded
	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	NS = Not Seeded in the North Area
June 20	9	—	1	—	9	—	2.3	—	
22	2072	535	15	4	138	134	21.3	65.4	NS
23	109	163	4	4	27	41	11.4	8.2	S
24	2996	—	29	—	103	—	87.4	—	NS
25	1383	567	16	7	86	81	50.9	52.9	S
26	1148	—	5	—	230	—	71.9	—	NS
27	1028	—	11	—	93	—	26.6	—	S
30	—	109	—	2	—	55	—	5.0	NS
July 1	3545	956	7	6	506	159	56.1	16.7	S
2	3020	852	11	3	275	284	59.2	38.9	NS
4	4690	277	10	2	469	139	89.0	25.2	S
5	12697	432	36	11	353	393	69.2	90.8	NS
6	3382	—	8	—	423	—	70.0	—	S
7	2954	557	14	3	211	186	27.2	39.2	S
9	1010	—	6	—	168	—	30.1	—	NS
22	—	1363	—	10	—	136	—	27.1	S
24	654	149	6	3	109	50	19.5	16.9	NS
25	2045	974	8	3	256	325	83.2	52.9	S
29	6498	409	34	4	191	102	84.1	13.2	NS
30	4106	31	32	2	128	15	65.5	1.8	S
Aug. 5	2702	103	10	2	270	52	82.8	18.9	S
6	1310	—	7	—	187	—	34.3	—	S
7	—	1056	—	6	—	—	—	53.9	NS
8	12640	—	36	—	351	—	62.8	—	S
10	4842	209	12	1	404	209	56.2	41.1	NS
11	878	—	4	—	220	—	21.4	—	S
13	2456	—	6	—	409	—	54.8	—	S
15	344	—	2	—	172	—	15.8	—	NS
17	124	401	1	2	124	201	16.6	22.1	S
18	11311	—	33	—	343	—	88.8	—	NS
24	64	137	2	1	32	137	3.3	17.4	S
Sept. 9	1199	—	3	—	400	—	37.9	—	S
	92952	13170	381	76	240	173	61.4	40.3	

TABLE 3

Summary of 1975 Hailpad Observations in the Precipitation and Dense Networks.

DATE	No. of Impacts Counted		No. of Pads Collected		Avg. No. Impacts Per Pad		Avg. I_E Per Pad ($J\ m^{-2}$)		Status of Day S = Seeded
	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	NS = Not Seeded in the North Area
June 3	1	—	1	—	1	—	.5	—	S
4	2	—	1	—	2	—	.3	—	S
5	18	—	1	—	18	—	2.2	—	S
6	1997	18	7	1	285	18	66.5	1.0	S
12	823	—	1	—	823	—	27.9	—	S
13	12096	5198	24	12	504	433	30.7	43.1	S
14	—	814	—	2	—	407	—	51.9	S
15	652	420	2	1	326	420	14.3	27.9	S
16	9931	7060	26	18	382	392	26.7	33.5	S
17	1416	—	4	—	354	—	36.9	—	S
19	280	—	2	—	140	—	19.1	—	S
20	3774	2230	9	2	419	1115	34.8	106.6	S
21	233	—	4	—	58	—	2.8	—	NS
23	910	—	11	—	83	—	26.0	—	S
25	19879	—	39	—	510	—	103.7	—	S
26	2589	341	5	1	518	341	29.8	446.1	S
28	1616	—	2	—	808	—	32.5	—	S
29	30	—	1	—	30	—	3.0	—	S
30	443	245	3	3	148	82	17.6	10.4	S
July 1	74	—	1	—	74	—	7.1	—	NS
2	1542	—	9	—	171	—	100.3	—	S
3	6097	1407	39	10	156	141	106.2	107.1	NS
4	7712	4788	36	17	214	282	91.2	198.5	S
5	146	—	2	—	73	—	81.9	—	S
6	7097	—	51	—	139	—	96.2	—	NS
14	86	—	1	—	86	—	6.6	—	S
15	117	—	1	—	117	—	17.9	—	NS
16	5847	3178	40	14	146	227	41.7	29.7	S
20	4159	2192	22	23	189	95	70.3	38.3	S
21	7776	3894	34	14	229	278	129.7	299.3	NS
26	227	—	1	—	227	—	32.4	—	S
28	349	—	2	—	175	—	34.6	—	S
Aug. 1	700	—	1	—	700	—	29.9	—	S
2	5764	2601	17	3	339	867	43.3	94.7	S
5	1964	—	24	—	82	—	90.5	—	S
6	2204	321	15	1	147	321	27.2	15.1	NS
7	272	—	3	—	91	—	9.7	—	NS
8	5772	—	19	—	304	—	36.2	—	S
10	1517	—	3	—	506	—	40.1	—	S
11	807	—	1	—	807	—	83.3	—	NS
20	2104	979	7	5	301	196	38.5	33.8	S
21	3583	3783	11	9	326	414	172.3	65.0	S
22	10998	4288	15	10	733	429	70.1	38.0	S
23	—	134	—	1	—	134	—	14.6	S
25	682	139	1	1	682	139	25.0	9.9	S
27	1083	—	1	—	1083	—	137.0	—	S
28	10255	16	50	1	205	16	57.0	1.9	NS
29	831	190	3	1	277	190	21.8	6.3	S
Sept. 3	669	—	1	—	669	—	12.7	—	NS
5	212	—	1	—	212	—	10.4	—	S
7	86	—	1	—	86	—	69.0	—	S
	147422	44176	556	150	265	295	69.9	88.9	

TABLE 4

Summary of 1976 Hailpad Observations in the Precipitation and Dense Networks.

DATE	No. of Impacts Counted		No. of Pads Collected		Avg. No. Impacts Per Pad		Avg. I_E Per Pad ($J\ m^{-2}$)		Status of Day S = Seeded
	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	NS = Not Seeded in the North Area
June 4	2021	31	2	1	1011	31	65.7	4.9	S
5	1100	392	7	3	157	131	3.7	4.4	S
9	897	—	5	—	179	—	7.5	—	S
12	614	—	5	—	123	—	6.4	—	NS
19	3384	565	13	4	260	141	33.4	51.2	NS
22	697	604	3	2	232	302	11.0	8.7	S
23	619	—	1	—	619	—	17.9	—	S
24	13195	10728	38	28	347	383	20.1	18.2	S
25	953	498	3	2	318	249	7.3	18.8	S
July 1	3799	1715	29	11	131	156	29.8	46.4	NS
4	84	—	4	—	21	—	3.4	—	NS
7	82	—	1	—	82	—	3.7	—	S
8	201	12	4	1	50	12	4.0	0.4	S
9	6413	—	22	—	292	—	79.4	—	S
13	2843	—	5	—	569	—	153.6	—	S
14	183	—	1	—	183	—	4.0	—	S
17	10104	15533	39	42	259	370	165.0	227.7	S
18	237	—	3	—	79	—	23.1	—	S
20	353	—	2	—	177	—	11.0	—	NS
21	10862	5937	44	21	247	283	64.7	57.0	S
26	199	—	1	—	199	—	10.2	—	NS
Aug. 6	1026	—	3	—	342	—	40.4	—	S
7	3335	—	10	—	334	—	62.6	—	NS
8	14490	2157	42	9	345	240	78.4	36.9	S
9	1522	1417	2	1	761	1417	118.0	161.4	NS
12	1793	1246	7	4	256	312	79.3	16.8	NS
14	1048	—	6	—	175	—	85.9	—	NS
15	11751	4978	65	25	181	199	54.6	80.2	NS
16	1568	—	8	—	196	—	27.4	—	NS
20	761	171	7	1	108	171	7.5	16.1	S
24	12	56	1	5	12	11	0.6	1.3	NS
Sept. 2	—	280	—	2	—	140	—	9.8	S
7	16	—	1	—	16	—	0.3	—	S
	96162	46320	384	162	250	286	61.1	90.5	

TABLE 5

Summary of 1977 Hailpad Observations in the Precipitation and Dense Networks.

DATE	No. of Impacts Counted		No. of Pads Collected		Avg. No. Impacts Per Pad		Avg. I_E Per Pad ($J\ m^{-2}$)		Status of Day S = Seeded
	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	NS = Not Seeded in the North Area
June 1	699	104	1	2	699	52	111.1	8.2	NS
2	1347	130	3	1	449	130	34.1	12.5	NS
11	—	10	—	1	—	10	—	0.2	NS
20	402	—	5	—	80	—	15.2	—	NS
21	—	45	—	1	—	45	—	2.6	S
22	9560	1755	33	17	290	103	28.9	8.1	S
23	—	111	—	1	—	111	—	5.5	S
25	190	—	5	—	38	—	1.7	—	S
26	3355	1256	35	12	96	105	28.1	6.9	S
27	—	1678	—	3	—	559	—	54.3	S
28	467	—	5	—	93	—	5.5	—	S
29	1277	—	1	—	1277	—	53.3	—	S
July 2	8147	—	21	—	388	—	25.2	—	S
3	—	21	—	1	—	21	—	0.4	S
5	1183	—	2	—	592	—	46.5	—	S
6	633	—	1	—	633	—	47.8	—	S
8	1216	—	5	—	243	—	8.9	—	S
9	7748	352	17	4	456	88	37.5	5.4	S
10	1166	2256	2	7	583	322	19.6	7.8	S
11	84	5	1	1	84	5	5.5	.1	NS
12	2100	—	3	—	700	—	136.0	—	S
14	1835	—	3	—	612	—	95.7	—	S
17	3725	724	14	5	266	145	15.2	5.7	S
18	13973	10959	32	34	437	322	25.1	10.0	S
19	3722	1627	11	6	338	271	13.0	13.8	S
22	2902	1923	25	17	116	113	18.6	11.2	NS
26	449	368	4	3	112	123	14.7	9.7	S
28	1966	—	12	—	164	—	14.1	—	S
29	1234	—	5	—	247	—	40.4	—	S
30	166	33	1	1	166	33	3.2	7.5	S
31	8235	1509	23	6	358	252	77.4	13.5	S
Aug. 2	658	—	3	—	219	—	38.0	—	S
3	724	—	5	—	145	—	3.8	—	NS
7	2103	—	5	—	421	—	233.8	—	NS
8	199	—	1	—	199	—	21.6	—	S
11	80	—	1	—	80	—	2.9	—	S
15	618	—	2	—	309	—	14.8	—	S
16	1427	—	3	—	476	—	77.3	—	S
19	279	83	1	2	279	42	15.3	9.8	S
25	166	891	1	3	166	297	6.0	9.9	NS
26	13608	7118	32	26	425	274	53.0	72.3	S
27	636	—	2	—	318	—	11.8	—	NS
Sept. 6	1115	1347	4	3	279	449	28.0	22.5	NS
7	11452	883	12	2	954	—	197.1	—	S
	110846	35188	342	159	324	221	41.1	20.7	

TABLE 6
Summary of 1978 Hailpad Observations in the Precipitation and Dense Networks.

DATE	No. of Impacts Counted		No. of Pads Collected		Avg. No. Impacts Per Pad		Avg. I_E Per Pad ($J\ m^{-2}$)		Status of Day S = Seeded
	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	Precip. Network	Dense Network	NS = Not Seeded in the North Area
June 5	49	844	1	1	49	844	5.9	127.4	NS
8	—	589	—	2	—	295	—	32.4	NS
9	1834	—	2	—	917	—	182.7	—	NS
10	21256	2352	26	5	818	470	93.2	73.0	NS
11	4312	770	11	1	392	770	46.4	105.7	NS
13	3824	2798	14	8	273	350	32.0	60.7	NS
14	1979	6620	7	11	283	602	32.8	89.0	NS
15	52626	24811	104	53	506	468	74.8	74.4	NS
16	13442	6712	18	15	747	447	86.3	49.5	NS
19	—	393	—	1	—	393	—	35.5	NS
20	—	776	—	3	—	259	—	48.0	NS
21	13793	656	29	1	476	656	80.9	63.4	S
22	14181	971	14	3	1013	324	165.0	36.3	S
23	2518	476	2	1	1259	476	162.0	57.9	NS
24	3634	—	5	—	727	—	102.9	—	S
29	14289	925	65	2	220	463	71.2	79.3	S
30	6102	666	18	3	339	222	68.3	52.4	S
July 2	—	76	—	2	—	38	—	6.5	S
3	4536	—	5	—	907	—	126.7	—	S
5	2465	2894	5	7	493	413	66.1	74.3	S
9	4958	—	4	—	1240	—	179.5	—	NS
10	16061	5226	56	21	287	249	51.9	34.7	S
11	583	34	2	1	292	34	74.5	5.6	NS
12	126	—	1	—	126	—	28.5	—	NS
13	5164	—	10	—	516	—	135.3	—	S
14	5816	19	12	1	485	19	156.7	1.5	S
15	7620	259	21	1	363	259	145.1	22.7	S
16	10405	396	27	4	385	99	77.1	13.7	S
17	500	250	1	2	500	125	39.7	14.4	NS
18	20999	1648	33	9	636	183	72.0	20.1	S
19	880	—	1	—	880	—	69.3	—	NS
20	738	—	2	—	369	—	45.9	—	S
21	11607	8055	21	24	553	336	84.4	43.4	S
22	2818	—	6	—	470	—	136.9	—	S
23	423	—	4	—	106	—	34.3	—	S
24	15	—	1	—	15	—	2.5	—	S
25	355	—	1	—	355	—	134.1	—	NS
26	1151	—	1	—	1151	—	102.0	—	NS
27	699	—	1	—	699	—	66.9	—	NS
28	2122	—	3	—	707	—	203.2	—	S
29	525	—	2	—	263	—	31.4	—	S
Aug. 7	115	—	1	—	115	—	14.3	—	S
10	934	242	2	3	467	81	87.6	10.6	S
11	2611	—	2	—	1306	—	260.1	—	S
12	7572	14649	6	8	1262	1831	213.3	340.8	S
13	—	516	—	1	—	516	—	45.0	NS
15	3423	—	10	—	342	—	63.4	—	S
18	2245	—	2	—	1123	—	162.7	—	S
23	—	85	—	1	—	85	—	9.9	NS
25	2550	5005	9	22	—	228	60.0	47.6	S
26	142	23	1	1	142	23	44.2	7.6	NS
31	428	—	3	—	143	—	15.1	—	S
Sept. 2	226	—	1	—	226	—	1.0	—	NS
3	1784	—	2	—	892	—	255.7	—	NS
18	500	—	1	—	500	—	43.0	—	NS
	276935	89736	576	218	481	412	83.7	64.2	

ATMOSPHERIC SCIENCES DIVISION
RESEARCH, OPERATIONS, AND EVALUATION
IN THE
ALBERTA HAIL PROJECT

1974 - 1978

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